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MONTHLY WEATHER REVIEW

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ON THE DESICCATION OF A CLOUD BANK BY A PROPAGATED PRESSURE WAVE [1]

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[Manuscript received February 19, 1951]

ABSTRACT

On December 6, 1949, an accelerated microbarograph in Washington, D. C., produced a unique pressure trace at the time that a peculiar cloud bank passed overhead. The rear (western) edge of this cloud bank ended very abruptly and had the appearance of an Antarctic ice barrier. A study of the synoptic conditions of the day revealed that this pressure variation was produced by an expansion-type pressure wave which travelled eastward from the Midwest and was propagated between two inversion surfaces with a speed far in excess of the wind speed in that layer. The cloud bank also travelled in this same atmospheric layer but was advected by the prevailing winds. The conclusion is reached that the pressure wave which progressively overtook the cloud bank was associated with a rapid drop of the isentropic surfaces which in turn produced the adiabatic heating necessary to desiccate the cloud partially in the Midwest and completely over Washington. Confirmation of this conclusion is found in solar radiation records.

INTRODUCTION

This study was motivated by two events which occurred simultaneously in Washington, D. C., on December 6, 1949. On the afternoon of that day a cloud bank appeared over the city. At about 1615 EST the cloud ended abruptly—like the pictures of an Antarctic ice cliff. This feature is shown in figure 1. This picture was taken facing eastward, so that the sun in the western skies brilliantly illuminated the edge of the cloud bank and showed it to be very thin. The author estimated it at the time as no more than 300–500 feet thick. This phenomenon traveled very rapidly eastward. The second phenomenon, which occurred at the same time that the western edge of the cloud bank passed overhead, was a pressure pulse which produced the barogram shown in figure 2. The microbarograph which recorded this trace is one with accelerated gears which records continuously on an attached Esterline-Angus Recorder. By expanding the time scale, finer detail in the variation of the pressure may be studied. This trace shows that with the passage of the "chopped off" portion of the cloud bank, the pressure dropped very suddenly and in a short time recovered suddenly. The simultaneity of the peculiar behavior of the cloud bank and the pressure trace suggested the possibility of some relationship between them. This study was a search for this relationship.

BAROGRAM INVESTIGATION

The history of the pressure pulse was studied through an investigation of the barograms for all the stations in the general neighborhood of Washington, D. C. Portions of these barograms are reproduced near their respective stations in figure 3. Care was taken in copying these traces to keep all the sheets oriented in exactly the same manner so that the pressure profiles of the stations and their slopes might be compared. The peculiar V-shaped pulse which was noted on the accelerated microbarograph at Washington could be traced back as far as western Pennsylvania, but not below the latitude of Washington, D. C. Furthermore, as western Pennsylvania was approached, the "first" part of the V-shaped pulse (i. e. the pressure fall) became the more pronounced while the rise diminished in amplitude. Continuing westward still

[1] Paper presented at the 109th National Meeting of the American Meteorological Society, New York City, January 30, 1951.

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FIGURE 1.—Cloud bank over Washington, D. C., on the afternoon of December 6, 1949. The photograph was taken looking eastward from the Washington Star building by the newspaper's staff photographer, Mr. Edward Baker. The picture is reproduced here through the courtesy of the Washington Star and Mr. Baker.

farther, one notices that this pronounced fall could be followed to western Indiana. In the Ohio-Indiana area, this fall was part of an over-all, but gentler pressure fall.

Isochrones of the passage of the V-shaped pulse to the east and the marked pressure fall to the west were drawn as indicated in figure 3. For the sake of uniformity, the time of onset of the fall was chosen throughout as the time designator for the isochrone. The two significant features of this isochrone pattern are:

(1) The pressure disturbance (which hereafter shall refer to both the V-shaped pulse to the east and the pressure drop to the west) can be followed only through the northern portion of the area studied. The southern portion shows gradual prolonged falls (particularly in the west) but no indications of a disturbance such as experienced farther north.

(2) The speed of the disturbance was approximately:

43 m. p. h. during 0800–1100 EST (in Indiana)
77 m. p. h. during 1100–1400 EST (in Ohio)
77 m. p. h. during 1400–1700 EST (in southern Pennsylvania and Maryland)

It should be indicated in passing that due to current practices of pressure recording by means of barographs the isochrones can be considered accurate only to about one-half hour.

CLOUD INVESTIGATION

A study of the Surface Weather Observations (W. B. Form 1130) for the stations in the area, revealed the following progression of cloud formations. The early part of the day was characterized either by clear skies or by the presence of thin, high clouds above 20,000 feet. Later in the day, each station reported the appearance of low clouds with bases varying from 5,000–10,000 feet. Finally, and this has only incidental significance for our purposes, most of the stations reported lower overcast. Our primary concern will be with the initial appearance of the

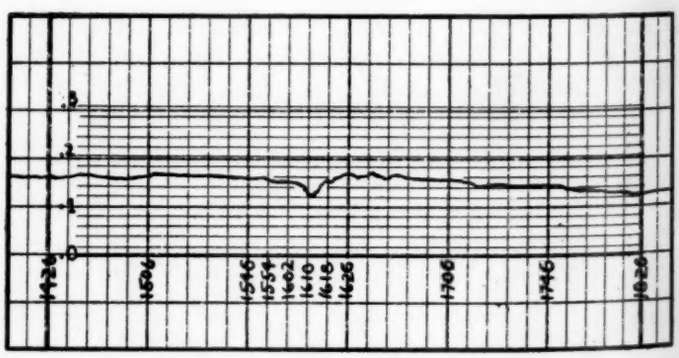

FIGURE 2.—Barogram, December 6, 1949, Washington, D. C

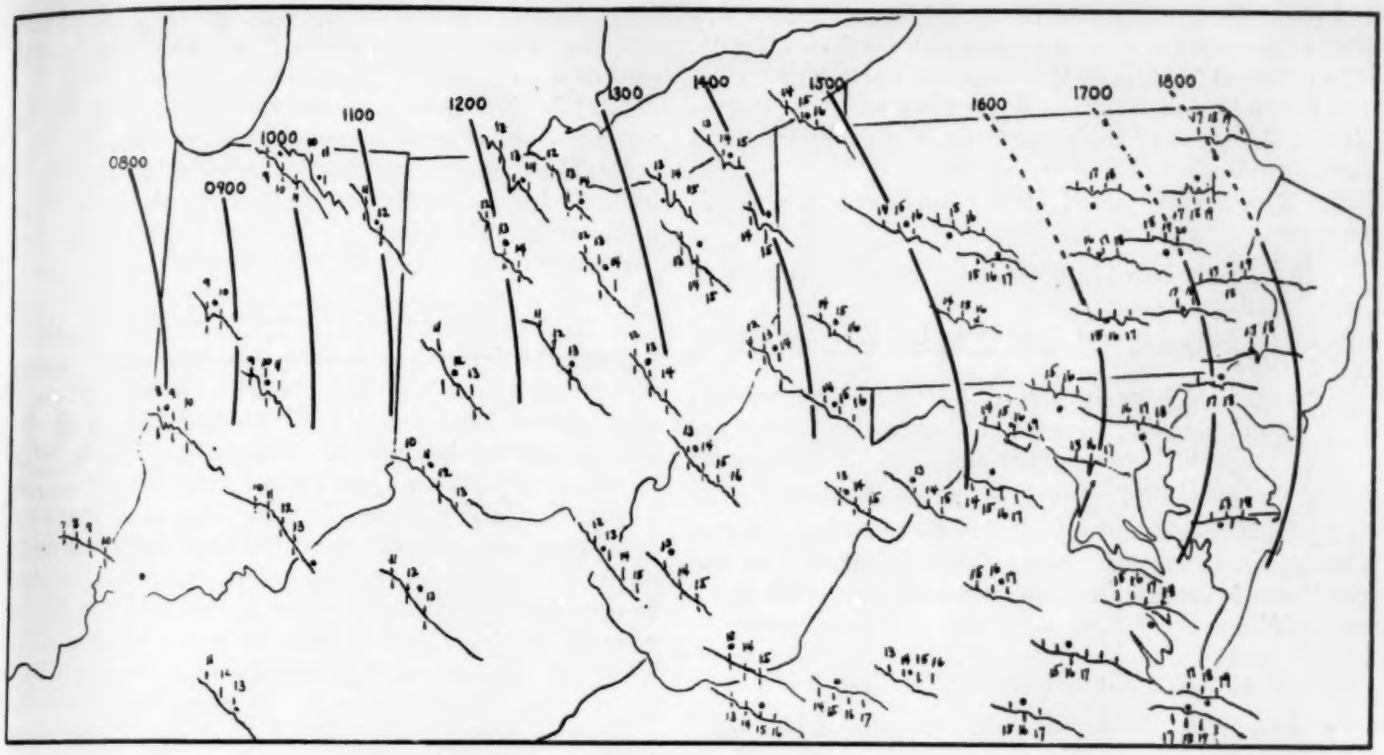

FIGURE 3.—Barograms, December 6, 1949, showing isochrones of pressure drop.

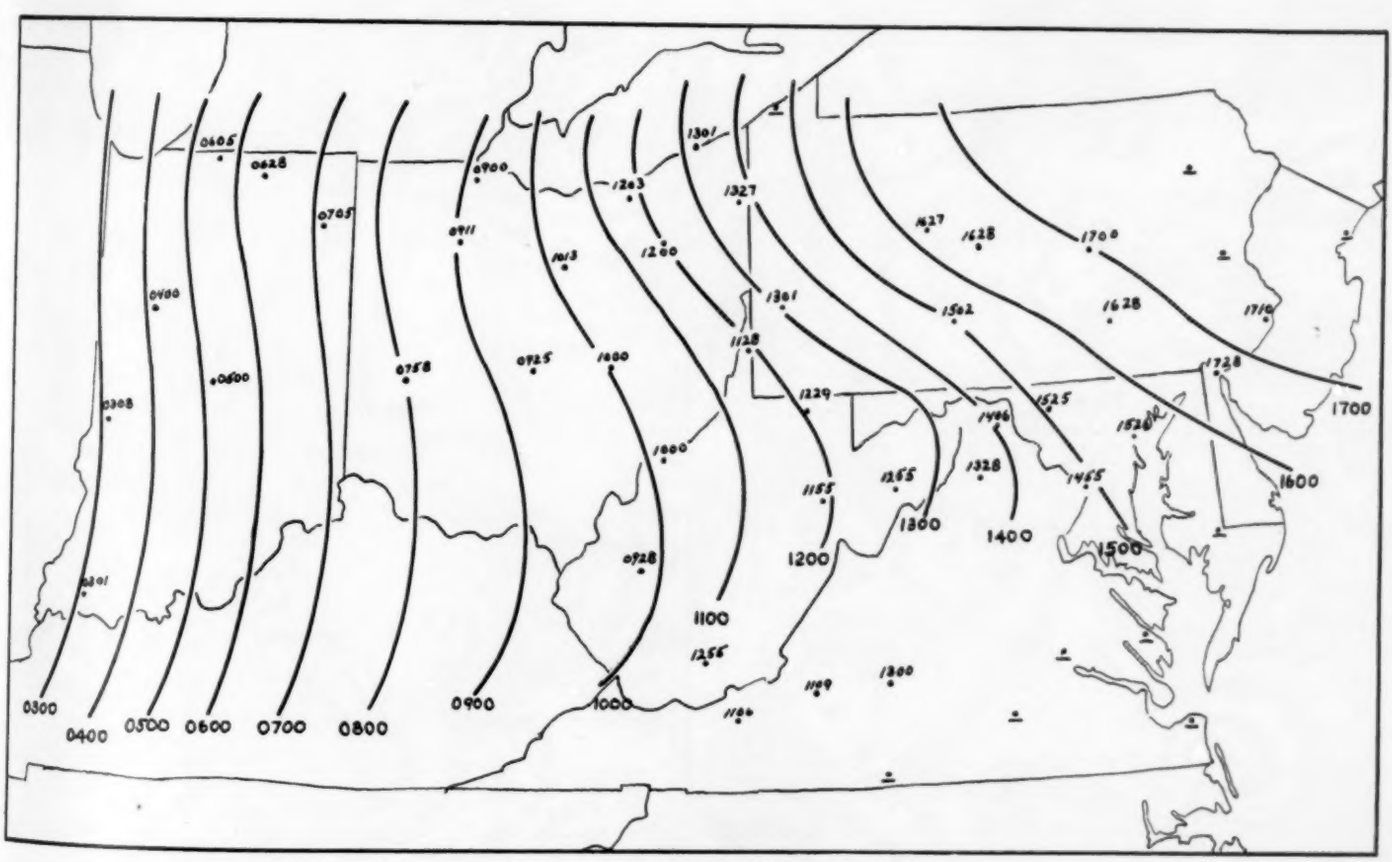

FIGURE 4.—Isochrone pattern for time of arrival of low cloud bank.

low cloud deck. The time of this initial appearance was plotted on a map and again isochrones were drawn (fig. 4). The principal features of this isochrone pattern are:

(1) The isochrone pattern indicates a uniform progression of the onset of the cloud bank in a general west to east direction.

(2) The average speed of the isochrones is approximately:

40 m. p. h. between 0500 and 0800 EST (in eastern Indiana)
50 m. p. h. between 0800 and 1100 EST (in central Ohio)
35 m. p. h. between 1100 and 1400 EST (in western Pennsylvania and western Maryland)
35 m. p. h. between 1400 and 1700 EST (in south central Pennsylvania and eastern Maryland)

Again, it should be kept in mind that weather observation practices cannot permit the consideration of the positions of these isochrones accurate to more than about one-half hour.

COMPARISON OF ISOCHRONE PATTERNS

A comparison of the pressure disturbance isochrone pattern with the onset of the cloud deck isochrone pattern shown in figures 3 and 4 reveals:

(1) East of Indiana the leading edge of the cloud bank travelled significantly more slowly than the pressure disturbance.

(2) The leading edge of the cloud bank preceded the pressure disturbance in time over most of the area.

(3) The pressure disturbance, travelling faster than the leading edge of the cloud bank, overtook the latter across a line roughly bisecting the State of Pennsylvania from the northwest corner to the southeast corner.

HOURLY SYNOPTIC MAPS

From the transmitted teletype data it was possible to plot hourly synoptic maps and analyze them. Four such maps drawn for 2-hourly intervals beginning with 1030 EST are shown in figure 5. The main synoptic feature on these maps is an open wave moving slowly through central Iowa and northern Illinois. The associated warm front stretches generally southeastward from the center of the wave. To the east, there is a pressure ridge which is also moving eastward. The position of the leading edge of the cloud bank is given by a line of open circles while the position of the pressure pulse is given by a thick line.

As may be expected, the leading edge of the lower cloud bank seems to coincide with the limit of the circulation around the wave. We may then attribute the cloudiness

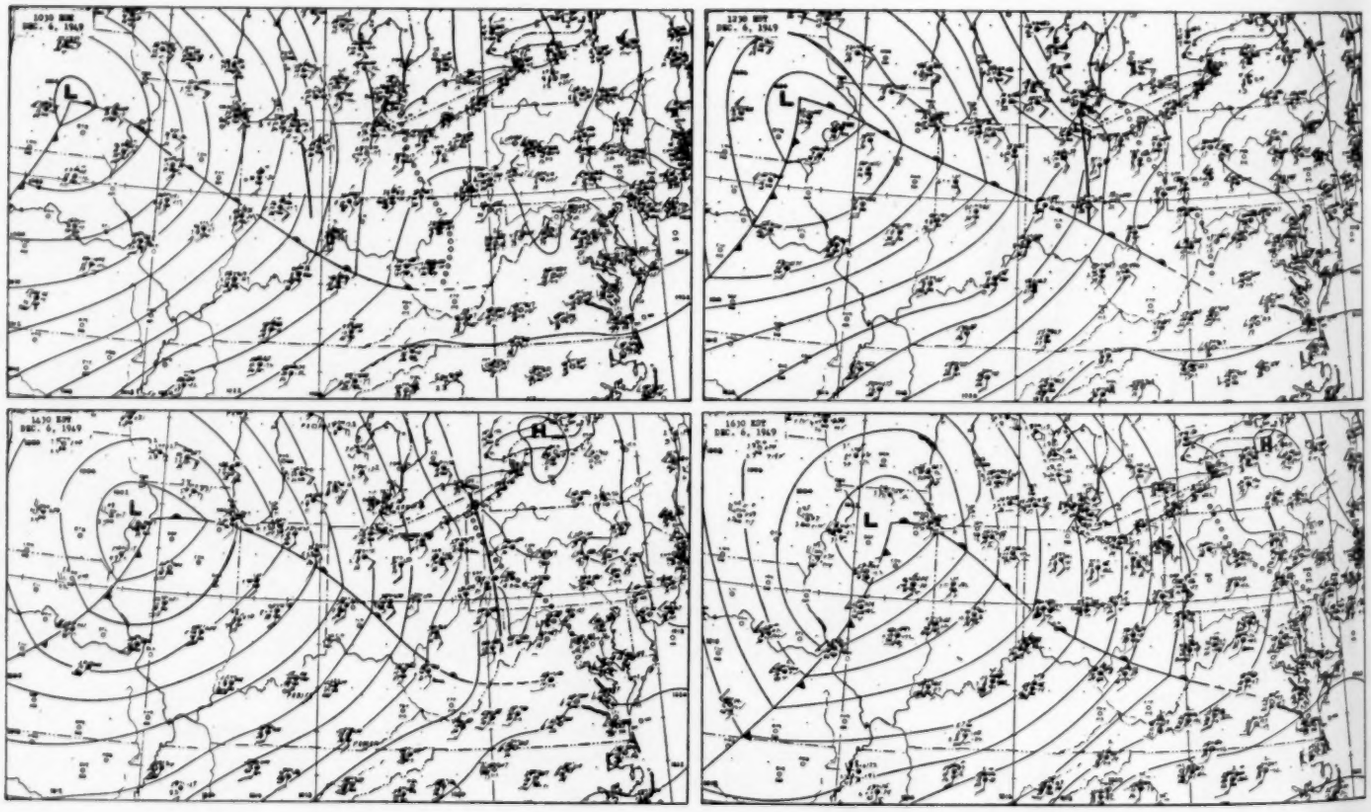

FIGURE 5.—Surface synoptic maps for 1030, 1230, 1430, and 1630 EST, December 6, 1949. Synoptic position of leading edge of cloud bank is indicated by line of open circles and the synoptic position of the pressure pulse by a thick solid line.

to overrunning or convergence which precedes a cyclone. On the other hand, the period of relatively clear skies may be associated with the anticyclonic circulation around the ridge.

The hourly synoptic maps graphically illustrate how the pressure disturbance travelled *through* the surface system. As the disturbance travelled away from the circulation around the wave and closer to the region dominated by the pressure ridge, its character changed from a pressure drop to a V-shaped pulse as identified in Pennsylvania, Maryland, and Washington, D. C. An explanation for this relationship will be given in a subsequent section.

It should be noted that throughout, the surface position of the warm front designates the southern limit for the pressure pulse isochrones.

WINDS ALOFT

It is, of course, of considerable importance to investigate whether or not advective processes could account for the propagation of either the pressure disturbance, the cloud bank movement, or both. Table 1, the wind data for 1000 EST and 1600 EST, shows that winds below 3 km. could have advected the cloud bank but not the pressure disturbance, while above 3 km. the winds were strong enough to have advected either or both. However, evidence will be presented in the next section to indicate that *the disturbance was probably propagated below 3 km.* and as such could not have been the result of an advective process.

CROSS SECTION

From the atmospheric soundings taken at Joliet, Toledo, Pittsburgh, and Washington, it was possible to construct a vertical cross section through the atmosphere for the time 1000 EST (fig. 6). At this time the pressure pulse was in a position indicated by the arrow and the leading edge of the lower cloud bank in the position indicated by the upright triangle. The wind data for Fort Wayne, Toledo, Columbus, Akron, Elkins, and Washington were superposed on the section. The winds were rotated in the plotting to conform to the orientation of the cross section. The important features of the cross section are:

(1) Isentropes: Above 4 km. the isentropic surfaces are pretty much horizontal and the atmosphere in this region represents quasi-horizontal homogeneity. Below 4 km. and east of Toledo the same situation prevails. The isentropic surfaces are again roughly horizontal. However, between the Toledo and Joliet soundings there is a marked change in the isentropic surfaces below 4 km. Interpreting this space cross section as reflecting the changes that would appear on a time cross section we may conclude that the potential temperatures indicate that subsequent warming has taken place. It should be noted that the isentropic surfaces were drawn to represent extremely rapid dropping of the isentropic surfaces in the area of the pressure pulse only, rather than a gradual descent from the values at Toledo to the values at Joliet. The reason for this analysis will be clear later.

(2) Inversions: The thick vertical lines represent elevations for which the soundings showed inversions of tem-

TABLE 1.—*Winds aloft (mph) at 1000 EST and 1600 EST, December 6, 1949*

Station \ Altitude	Surf.	500	1000	1500	2000	2500	3000	4000	5000	6000	7000	8000	9000 meters
1000 EST													
Evansville, Ind	SSW 16	SW 40	WSW 63	WSW 58	WSW 56								
Fort Wayne, Ind	SE 11	SE 31	S 36	SW 29	WSW 36	WSW 43							
Indianapolis, Ind	SSE 13	SSW 29	SW 34	SW 36	WSW 43								
Akron, Ohio	S 5	S 7	W 11	W 22	W 36	WNW 45	W 45	W 81	WNW 96				
Cincinnati, Ohio	SSE 9	SSW 27	WSW 36	WSW 36	WSW 43								
Columbus, Ohio	SSE 5	SSE 18	SW 18	W 27	W 34	W 43							
Toledo, Ohio	SE 9	SE 13	SSW 20	SW 20	W 31	W 38	W 38						
Curwensville, Pa	NW 13		WNW 31	WNW 40	WNW 49	WNW 56	WNW 63						
Harrisburg, Pa	W 16	WNW 22	WNW 22	WNW 20									
Philadelphia, Pa	WNW 18	W 16	NW 29	WNW 43	WNW 58	NW 67	NW 74						
Elkins, W. Va	WSW 9		W 13	WNW 31	WNW 45	WNW 47	WNW 67	WNW 76	W 90	WNW 87	WNW 105		
Norfolk, Va	WNW 11	W 31	W 20	NW 25	NW 40	NW 50	NW 60	WNW 72					
Richmond, Va	W 9	WSW 22	W 16	WNW 22	NW 44	NW 58	WNW 67	WNW 81	WNW 98	WNW 116	WNW 119	WNW 98	WNW 154
Roanoke, Va	WSW 9	WSW 9	WNW 16	WNW 36	WNW 50	WNW 56	WNW 54	WNW 74	WNW 81	WNW 81	WNW 85	WNW 87	WNW 87
Washington, D. C	WSW 16	W 18	WNW 27	WNW 49	NW 56	NW 56	NW 67	WNW 78	WNW 107	WNW 114	WNW 112		
1600 EST													
Evansville, Ind	SSW 18	SSW 43	SW 45										
Fort Wayne, Ind													
Indianapolis, Ind	S 11	SW 34											
Akron, Ohio	SE 9	SE 18	S 29	SW 9	SW 27								
Cincinnati, Ohio	SSW 25	SSW 38	SW 54	SW 56									
Columbus, Ohio													
Toledo, Ohio	ESE 20	SE 29											
Curwensville, Pa	SW 7		WSW 5	WNW 18	WNW 40	WNW 49	WNW 60						
Harrisburg, Pa	WSW 5	W 9	W 16	WNW 34	WNW 49	WNW 52	WNW 52	W 87	W 87	W 90			
Philadelphia, Pa	WNW 9	WNW 20	W 25	WNW 36	WNW 47	WNW 49							
Elkins, W. Va	S 5		SW 18	WSW 38	W 47	W 49							
Norfolk, Va	WSW 9	WSW 20	WSW 20	WNW 31	NW 38	WNW 47							
Richmond, Va	SW 5	SW 9	WSW 13	W 27	WNW 63	WNW 60	W 58	W 65					
Roanoke, Va	SW 9	SW 16	SW 22	WSW 29	W 38	W 47	W 56						
Washington, D. C	WSW 2	SW 11	WSW 20	WNW 34	WNW 49	WNW 55							

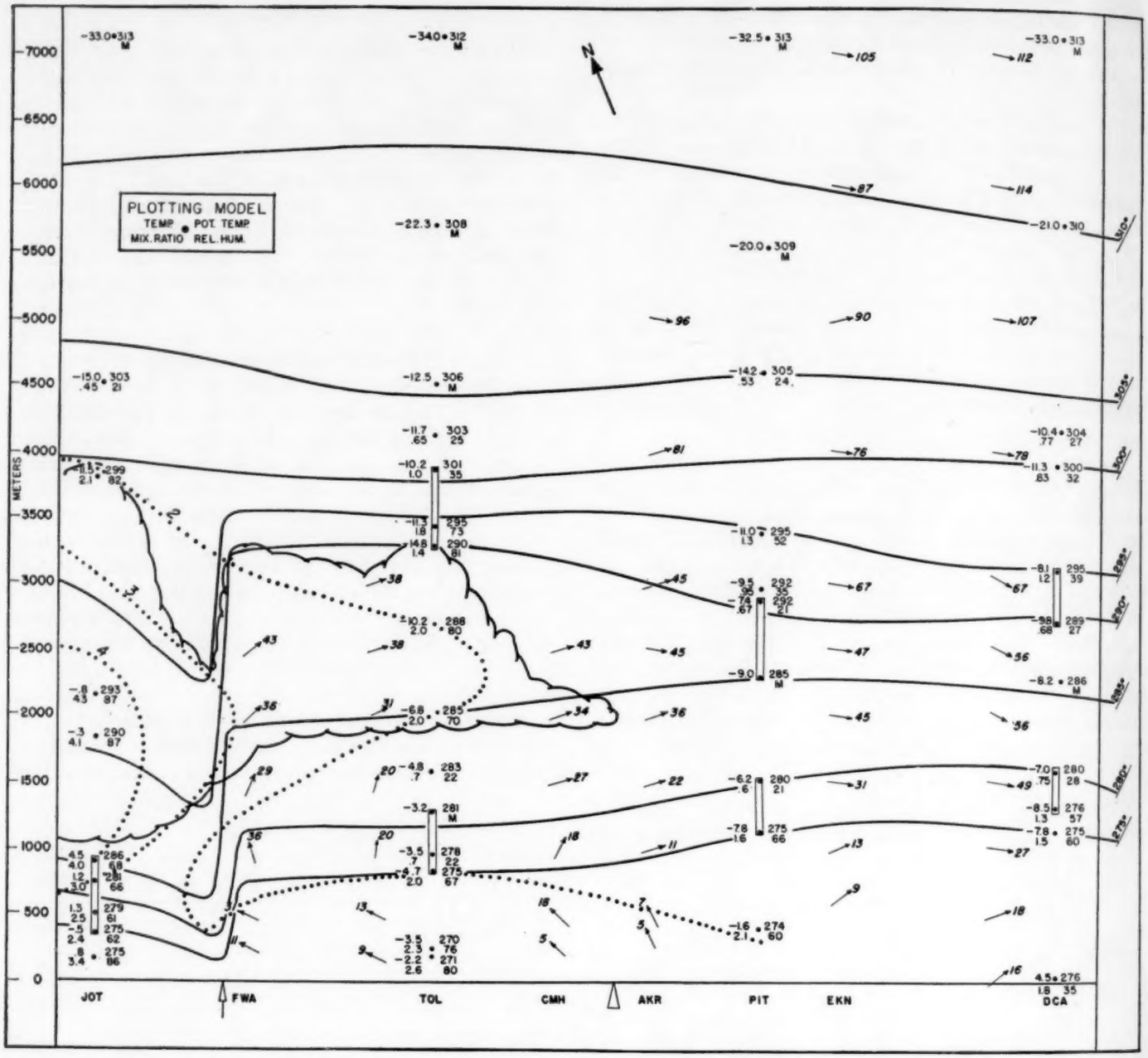

FIGURE 6.—Atmospheric cross section, Joliet—Washington, 1000 EST, December 6, 1949. Solid lines are isentropes (° A), dotted lines are lines of equal mixing ratio (gm./kg.), upright rectangles are temperature inversions. Along the bottom of the chart, arrow represents location of pressure pulse and upright triangle the leading edge of the cloud bank. The winds (in m. p. h.) are plotted with reference to the directional arrow in the top center. JOT=Joliet, FWA=Fort Wayne, TOL=Toledo, CMH=Columbus, AKR=Akron, PIT=Pittsburgh, EKN=Elkins, DCA=Washington.

perature. It should be noted that from Toledo and eastward there are two distinct inversion surfaces; the lower at approximately 1,000 m. and the upper one at approximately 2,000–3,000 m. The lower inversion was associated with the warm front to the south. At Joliet, only the lower inversion is present and it has lowered between 300 and 500 m. The upper inversion has been almost eliminated undoubtedly due to the warming that has been discussed above. (A remnant of the upper inversion may still be found over Joliet at 2 km.)

(3) Moisture and clouds: The cloud bank has been drawn in the regions where the relative humidity was greater than 70 percent. It should be noted that the cloud bank appears to travel in between the two inversion layers. At the point where the isentropic surfaces were drawn to dip down very sharply, the cloud pattern was drawn in a manner to conform with this adiabatic heating. Similarly, the isentropic surfaces were lifted over Joliet which reported higher humidities. This feature will be discussed in greater detail in the subsequent sections.

(4) Winds: Below the lower inversion the winds are predominately easterly. Between the two inversions they change to westerly and are of the same speed as the speed of propagation of the cloud bank. Above the second inversion the winds are very strong, but here nothing seems to be happening. It is of particular interest that the winds over Fort Wayne, below the lower inversion are much faster (easterlies) than the winds at Toledo, Columbus, or Akron.

EASTERLY WIND COMPONENTS

This increase in the easterly wind component may be seen in figure 7. Here the reported winds at various stations have been broken down into their components and the *easterly* component plotted with respect to position of the passage of the pressure pulse. It can be seen that there are definite indications of an increase in the easterly wind component associated with the passage of the pressure pulse. The wind values plotted are not continuous but represent discrete wind observations taken at relatively long-period intervals. Continuous records might have indicated this behavior much more clearly.

HYDRAULIC EXPERIMENT

In setting up a hypothesis to explain the phenomena described above, it will be helpful first to consider the following laboratory experiment (fig. 8 A, B, C). Water is made to flow in a trough (60 by 6 by 2 inches) from right to left. By adjusting the opening at the left a constant level of water is maintained (fig. 8A). (The size of the opening is controlled by sliding a plate up or down.) The plate is suddenly raised (fig. 8B) allowing the water to accelerate to the left. This produces a depression of the water surface which *travels to the right*. The plate is suddenly lowered (fig. 8C) to its original position and the water which has been accelerating piles up and raises the water surface. This elevation of the water surface also *travels to the right* behind the depression.

By analogy to gas flow, we may refer to the traveling depression of the water surface as an expansion type wave and the subsequent elevation of the water surface as a compression type wave. It is emphasized that *both the expansion and the compression type waves* travel in a direction opposite to that of the flow of the water.

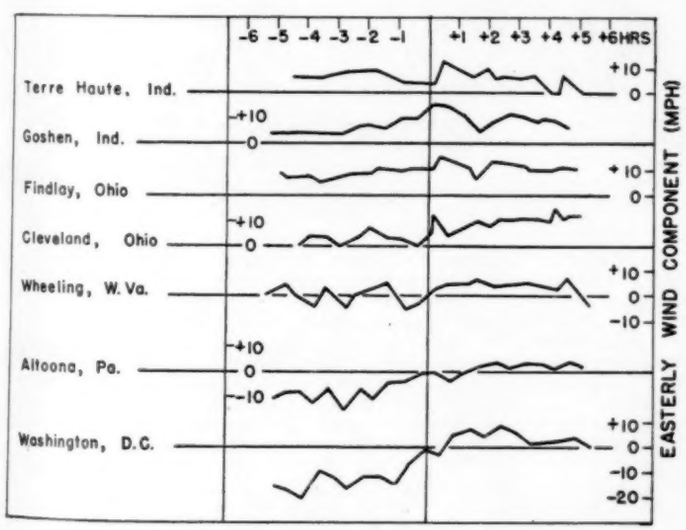

FIGURE 7.—Easterly wind component (m.p.h.) in relation to the passage of the pressure pulse.

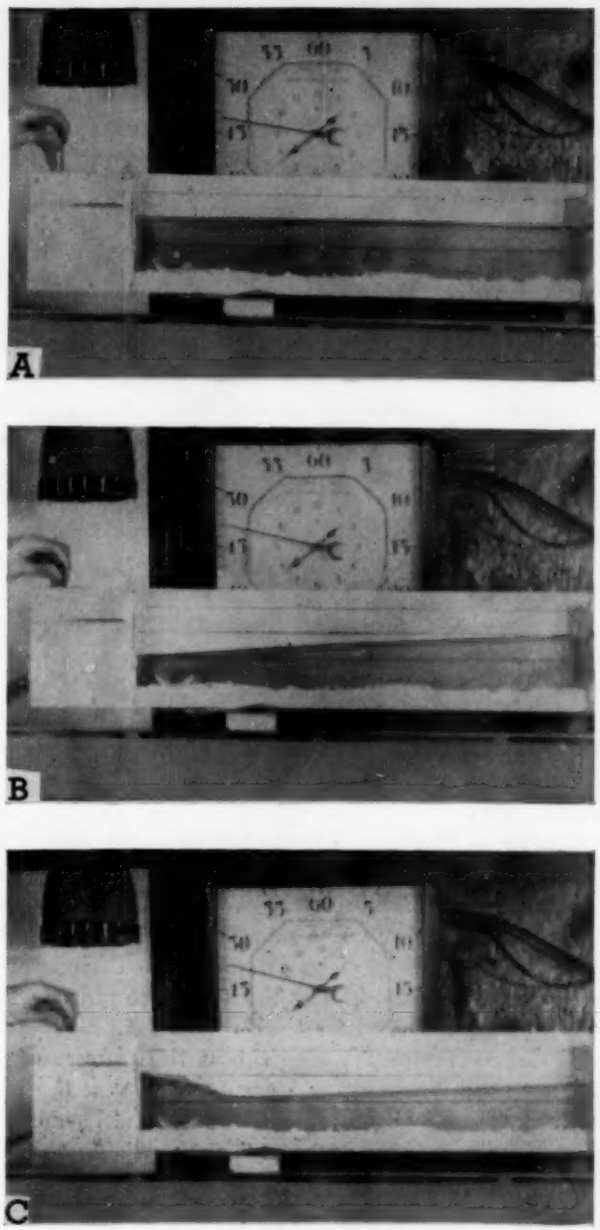

FIGURE 8.—Hydraulic experiment. (A) Steady state conditions; the water is flowing from right to left and the level of the water is maintained constant. (B) The plate at the left is lifted producing a drop of the water surface. The wave moves to the right. (C) The plate at the left is lowered to its original position producing an elevation of the water surface. This wave also moves to the right. (The bottom surface of the trough is perfectly smooth. The apparent roughness is due to paint along the edge of the glass.)

THE HYPOTHESIS

Freeman [2] has indicated the conditions under which the flow of air under an inversion surface may be considered analogous to the flow of water in an open channel. In this analogy, the inversion surface corresponds to the free surface of the water, and variations of the height of the inversion surface behave in a manner similar to water waves. In particular, waves on the inversion surface would be propagated independent of the flow of the air particles themselves.

We postulate then, that some mechanism accelerated the air below the warm frontal inversion. As in the case of the water in the laboratory experiment the inversion surface dropped suddenly, producing an expansion-type wave which moved eastward. The second phase of the pressure pulse is associated with the compression-type wave produced as the accelerating air is slowed down by convergence with the air ahead of it. It would be expected from hydrostatic reasoning alone, that the expansion-type wave would be reflected as a pressure drop at the surface and the compression-type as a pressure rise. This combination of pressure fall followed by a pressure rise when superposed on a falling pressure field would produce the type of trace characteristic of the Midwest. When this pulse reached the flat pressure area in the East it appeared primarily as a V-shaped pulse.

Now, associated with the rapid fall of the inversion surface there would be rapid heating and consequent desiccation of part or all of the cloud. We should then expect that when the pressure wave traverses an area where the cloud is relatively thick that its power to desiccate the cloud completely would be less than in those places where the cloud was relatively thin.

Returning to figure 1 which shows the picture of the cloud bank over Washington, we may state that the pressure wave had just caught up to the cloud and because the cloud was very thin, the pressure wave was able to desiccate the cloud completely.

SOLAR RADIATION

While the physical interpretation given above explains the peculiar phenomenon that passed Washington, D. C. on December 6, 1949, it also raises the obvious question, did this phenomenon happen only at Washington or did it occur elsewhere? The answer is that the basic phenomenon did occur elsewhere but on a different scale. The evidence for this statement lies in solar radiation data.

We shall assume here that sudden changes in transmission are probably caused by sudden changes in the thickness of the intervening cloud layer. While it is conceded that changes in transmission may also be caused by changes in the water content and/or drop size in the cloud layer, it will be safe to assume that the sudden changes in transmission that will be shown were probably caused by decrease in thickness of the cloud layer.

Figure 9 shows the radiation traces from Indianapolis, Columbus, Put-in-Bay, Cleveland, and Washington. For comparison the radiation trace for a relatively clear day at each station is shown by the dashed line.

The general feature of all these traces is that they contain two significant points. The first is a decrease in radiation and the second is a very sharp increase in radiation. Some of the time scales are in Solar Time and so a conversion to Eastern Standard Time is required. This conversion factor is shown where required. The time of occurrence of each of the two significant features from each trace was recorded and compared with the isochrone pattern for the onset of the low cloud bank and the passage of the pressure pulse. This comparison is shown in table 2. The two columns refer to the time of decrease in radiation and the time of sudden increase in radiation. The numbers in parentheses refer to the time that the lower cloud bank appeared over the station as reported on the Surface Weather Observation Sheet. The numbers in brackets refer to the time of the passage of the pressure pulse over the station as recorded on the microbarograph trace.

Considering the errors that may arise in reading the traces, the difference in location of the instruments at any one city, and the possible lack of accurate time considerations in taking observations, the agreement in the time values is remarkable. We may safely associate the decrease in radiation with the onset of the cloud bank and the sudden increase in radiation with the passage of the pressure pulse.

TABLE 2.—*Times of sudden decrease and increase in solar radiation. Figures in parentheses refer to time of arrival of the cloud bank and figures in brackets to time of passage of pressure pulse*

	Time (EST)			
	Decrease		Increase	
Indianapolis, Ind.	----	(0500)	0922	[0920]
Columbus, Ohio	0914	(0925)	1148	[1215]
Put-in-Bay, Ohio	0947	(1000)	1240	[1230]
Cleveland, Ohio	*1200	(1203)	1315	[1320]
Washington, D. C.	1455	(1455)	1602	[1610]

*The fluctuations in radiation at Cleveland, beginning with 0950 are related to a few scattered Cu. which were reported on the Surface Weather Observations Form beginning at 0900. These clouds were reported under "Remarks." Lower clouds were not reported under "Sky Conditions" until 1203 and this entry was undoubtedly associated with the continuous decrease in radiation beginning at 1200. Surface Weather Observations Forms are not available for Put-in-Bay so that it is not possible to determine whether the fluctuating transmission after 0947 was due to scattered clouds at the leading edge of the cloud bank or scattered clouds unrelated to the cloud bank. The records from Toledo seem to indicate 0900 as the time when the leading edge of the cloud bank moved in at Toledo. It is for this reason that 0947 was chosen as appropriate for Put-in-Bay.

CONCLUSION

We conclude from the evidence presented in this study that a pressure wave consisting of a pressure drop followed

[2] J. C. Freeman, Jr., "An Analogy Between Equatorial Easterlies and Supersonic Gas Flow", *Journal of Meteorology*, vol. 5, No. 4, August 1948, pp. 138–146.

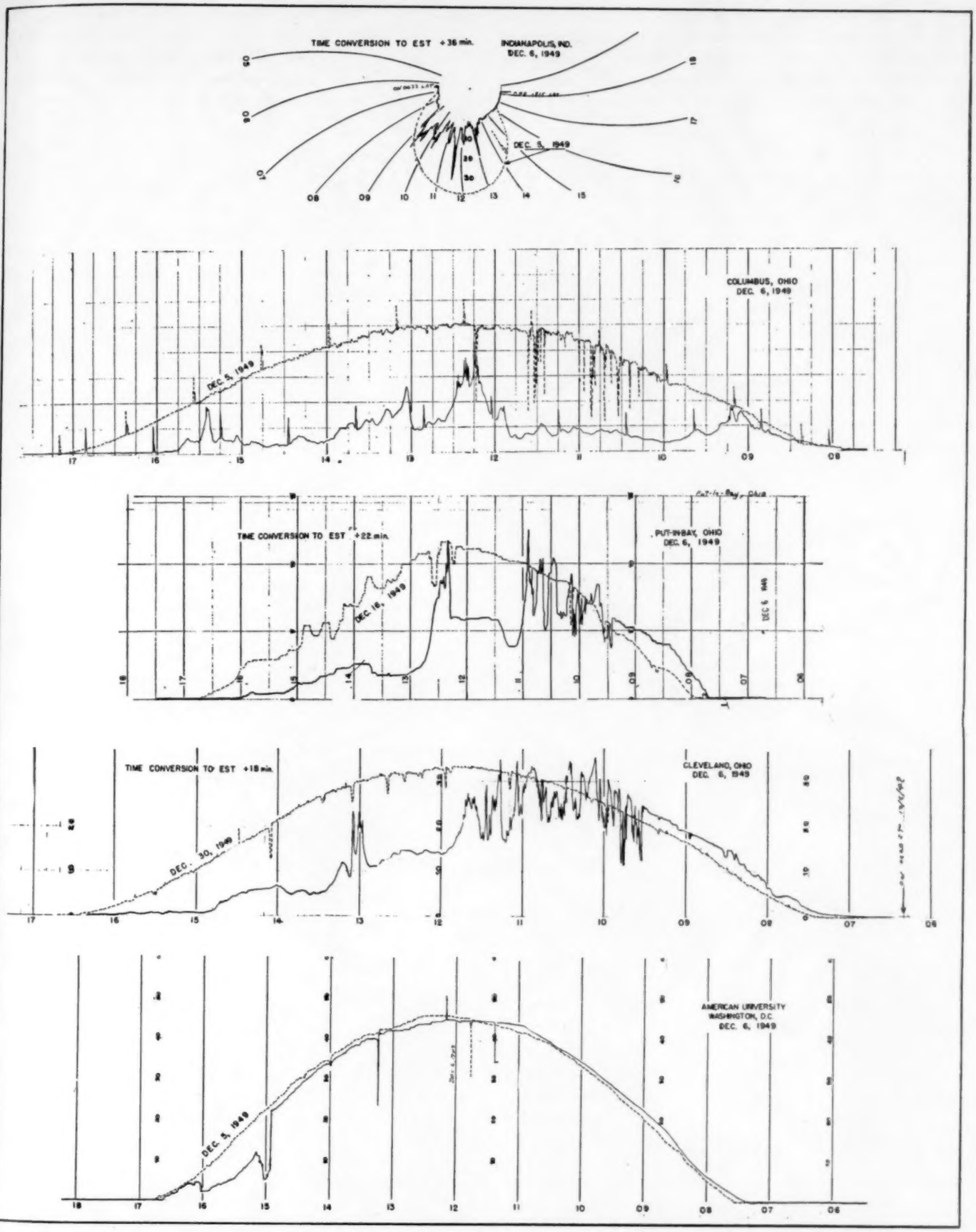

FIGURE 9.—Radiation traces for Washington, D. C., Cleveland, Ohio, Put-in-Bay, Ohio, Columbus, Ohio, and Indianapolis, Ind., December 6, 1949. A relatively clear-day radiation trace is indicated by the dashed line.

by a pressure rise, was propagated on the warm frontal surface with a speed far in excess of the winds in the lower layers. This wave was produced by sudden acceleration in the winds below the frontal surface. The pressure drop which is but an indication of the sudden fall in the isentropic surface was associated with a partial (in the Midwest) and total (over Washington) desiccation of the cloud layer. We leave unanswered the question: what is the mechanism that produced the sudden acceleration of the winds below the inversion surface?

THE WEATHER AND CIRCULATION OF APRIL 1951

JAY S. WINSTON

Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

CIRCULATION FEATURES

Over most of the Western Hemisphere during April 1951 the mean circulation at both sea level and aloft (Charts XI–XV)[1] was dominated by low index features. This is demonstrated most clearly by the fields of pressure and height departures from normal in chart XI inset and figure 1. Note the predominance of below-normal sea level pressures and 700-mb. heights at lower latitudes (south of about 45° N.) from the west coast of Africa westward through virtually all of the southern Atlantic and the United States into the southeastern Pacific. Meanwhile at middle and higher latitudes (north of about 45° N.) sea level pressures and 700-mb. heights were markedly above normal from mid-Atlantic westward to the eastern Pacific. The centers of positive 700-mb. height anomaly (fig. 1) were located in or near pronounced ridges in the Atlantic and eastern Pacific while the negative centers were associated with deep troughs at middle and low latitudes in the eastern Atlantic, the Great Lakes—Mississippi Valley region, and off the coast of Lower California. Heights in the Canadian Arctic were again strongly above normal as they had been in March.

[1] See charts I–XV following page 80 for analyzed climatological data for the month.

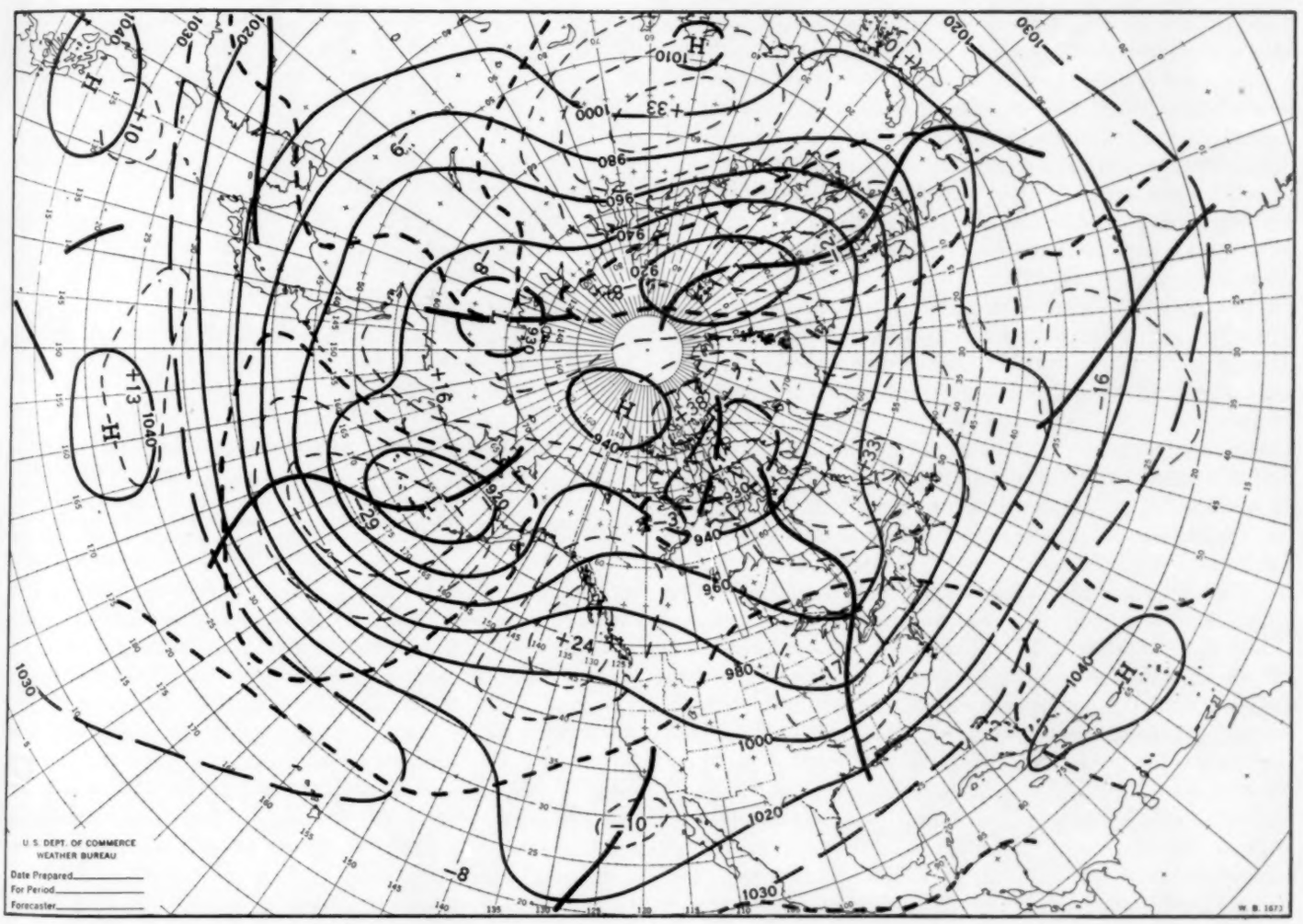

FIGURE 1.—Mean 700-mb. chart for the 30-day period March 31–April 29, 1951. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft intervals by lines with short dashes with the zero isopleths heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

In general the height anomaly picture over the Atlantic and northern Canada was quite similar to the preceding month [1]. The persistence of a blocking-type pattern in the Atlantic did not occur in mid-Pacific, however. In that region a deep Aleutian Low and a broad cyclonic circulation to its south were present (fig. 1) where a blocking ridge had existed in March [1]. Another noteworthy feature of the circulation was the deep trough over Western Europe. This marked the tenth consecutive month that heights had been below normal in the vicinity of the British Isles.

Further details of the Western Hemisphere circulation in April 1951 are revealed by the field of mean 700-mb. geostrophic wind speed shown in figure 2. Characteristic of the low index state over the area from Europe westward to the eastern Pacific was the split monthly mean jet stream with one branch between 55° and 65° N. and the other between 25° and 40° N. From Lower California eastward to the central Atlantic the southern branch of the jet was much stronger than the northern branch. The highest wind speeds in the jet, as much as 15 m. sec.$^{-1}$, were observed over the Carolinas on the east side of the deep United States trough. Between these two jets monthly wind speeds were generally quite weak as indicated by the minimum speed centers over the eastern Atlantic, Newfoundland, James Bay, and California. The only portion of figure 2 in which the jet stream was not split was in the central Pacific where the winds blew in a broad, rapid stream on the south side of the deep Aleutian Low (fig. 1).

The cyclone tracks (Chart X) reflected some of the effects of low index and blocking action which prevailed during April 1951. On many occasions storms moved very slowly, followed looping paths, and traveled with pronounced meridional components. This cyclonic activity was generally most concentrated in the regions of cyclonic vorticity at 700 mb. (fig. 3). Note the clustering of cyclone tracks in the centers of cyclonic vorticity in the Aleutian Islands-Gulf of Alaska region, in the Pacific off California, in the Midwest, to the south of Newfoundland, and at lower latitudes in the eastern Atlantic.

Most of the areas of cyclonic vorticity at 700 mb. coincided with low pressure centers or troughs at sea level (Chart XI). The major path of storms across the United States was from the Colorado-Texas Panhandle region northeastward to the Lakes and thence eastward to near Newfoundland. This track followed the channel of cyclonic vorticity across the country (fig. 3) more closely than it did the mean 700-mb. contours (fig. 1). It is important to point out that cyclonic activity generally was at a minimum in regions of pronounced anticyclonic vorticity aloft. For example, note the lack of storminess in the Pacific off the Washington-Oregon Coast (Chart X) associated with the anticyclonic vorticity center there (fig. 3).

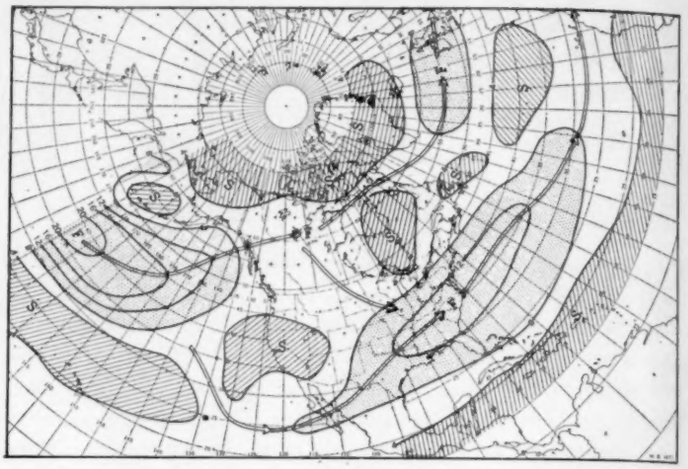

FIGURE 2.—Mean geostrophic (total horizontal) wind speed at 700-mb. for the 30-day period March 31–April 29, 1951. Solid lines are isotachs at intervals of 4 m./sec. while the double arrowed lines delineate the axes of maximum wind speeds (jets). Areas with speeds in excess of 8 m./sec. are dotted while those less than 4 m./sec. are hatched. Centers of maximum and minimum wind speed are labeled "F" and "S" respectively.

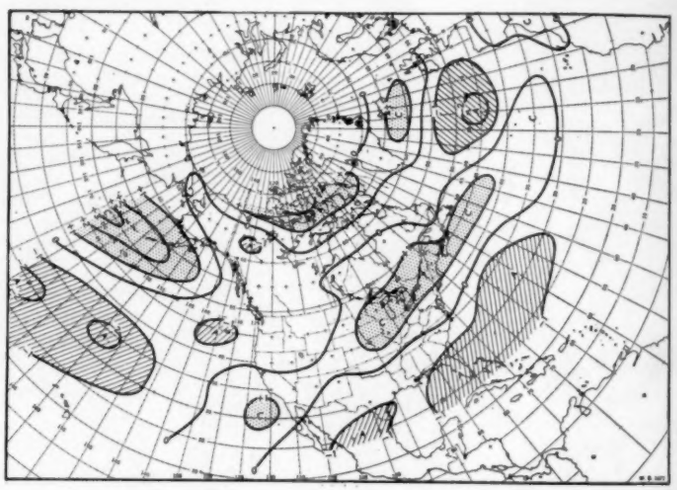

FIGURE 3.—Vertical component of mean relative geostrophic vorticity at 700-mb. for the 30-day period March 31–April 29, 1951, in units of 10^{-5} sec.$^{-1}$. Areas of cyclonic vorticity in excess of 1×10^{-5} sec.$^{-1}$ are dotted and labeled "C" at the center; areas of anticyclonic vorticity less than -1×10^{-5} sec.$^{-1}$ are hatched and labeled "A" at the center.

The vorticity chart (fig. 3) is also of interest in relation to the tracks of anticyclones shown in Chart IX. In the eastern Pacific, anticyclones were concentrated in regions of anticyclonic vorticity. In addition, anticyclones moved out of Canada along the channel of anticyclonic vorticity toward the strong center in the eastern Atlantic. A similar relationship was also evident in the Gulf of Mexico. However, several Highs traversed the United States from the Northern Plains and Canada through the Midwest and into the Atlantic across the North and Middle Atlantic States. This path took them through the pronounced cyclonic vorticity region shown in figure 3. Two of these anticyclones (those which were located in western Nebraska on the 16th and 22d) were shallow cold Highs which followed the cyclonic steering current of the mean 700-mb. flow (fig. 1).

THE WEATHER

The general temperature anomaly pattern over the United States during April 1951 (Chart I inset) was remarkably reminiscent of more than half the months of 1950.[3] Once again temperatures averaged below normal in a broad zone from the northern Rockies southeastward to Florida. This cold weather was associated with the combined action of the deep trough in the Great Lakes-Mississippi Valley region and the strong ridge in western Canada in transporting cold polar air into the Central States (fig. 1). Thus, the greatest negative temperature anomalies occurred in the Plains to the rear of the trough where the 700-mb. flow was northerly relative to normal. Cold air was also shunted into the Southeast because of the blocking action in the Northeast and eastern Canada. The fast westerly flow in the South (fig. 2) and the below-normal 700-mb. heights were concomitantly connected with the cool weather in the Southeast.

The southeasterly and easterly drift relative to normal at 700 mb. into the Northeast and Great Lakes regions continued to keep temperatures in those areas well above the normals. This was the seventh consecutive month in which New England had above normal temperatures. This condition was largely due to the persistent recurrence during most of these months of warm anticyclonic conditions in eastern Canada and the western Atlantic and accompanying oceanic flow into New England at both sea level and aloft [2, 3].

In the Far West April temperatures were above normal under the influence of above-normal heights and anticyclonic conditions aloft in the Northwest (fig. 1), and due to prevailing continental drift at sea level (Chart XI) and with respect to normal at both sea level (Chart XI inset) and aloft (fig. 1) in the Southwest. Thus, even with below-normal heights aloft in the Southwest, temperatures remained above normal since there was little opportunity for strong influxes of cool Pacific air into the region during this month.

To the east of the major trough extending from the Great Lakes southward into the lower Mississippi Valley (fig. 1) precipitation amounts were generally heavier than the normals for April (Charts III-A and B). However, the fact that few storm centers passed through this area (Chart X) was probably responsible for the spots of subnormal precipitation scattered through the eastern third of the country. This was especially noticeable in east coastal sections from Virginia to Massachusetts where precipitation amounts were as low as 60 percent of normal.

The belt of heavy precipitation extending from the Central Plains northeastward to the upper Lakes (Charts III-A and B) aggravated the critical flood situation in the upper Mississippi River Basin. These floods began late in March [1], became very serious in the first half of April, and finally subsided in the second half of the month. This precipitation was associated with the major storm path just to the southeast of the region (Chart X) and cyclonic vorticity aloft (fig. 3).

At Omaha this was the wettest April on record. At Madison, Wis. and Lincoln, Nebr. the amount of solar radiation received at the ground was markedly less than normal (Chart VIII inset). These observations were in agreement with the excessive cloudiness (Chart VI–B) and subnormal sunshine (Chart VII–B) throughout this zone of heavy precipitation. Other regions between the Mississippi Valley and the Rockies were generally drier than normal since they were located in the northwesterly flow to the rear of the upper level trough (fig. 1) where cyclonic activity was at a minimum. Large portions of Texas, where anticyclonic vorticity prevailed aloft (fig. 3), were extremely dry during the month as precipitation amounts totaled less than 25 percent of normal.

Considerable precipitation occurred in the normally dry Southwest in April. This was obviously attributable to the pronounced mean trough off Lower California (fig. 1) which brought moist Pacific air into coastal California and the inland desert regions. In southern Arizona the rainfall amounts totalled more than 400 percent of normal (Chart III–B). As the western trough intensified and built northward in the last week of the month a deep cyclone traversed the Basin region toward the northeast (Chart X). As a result considerable amounts of snow and rain fell throughout the Far West. This precipitation broke one of the most pronounced April dry spells on record in the Northwest. Associated with the dry regime in this area was the pronounced mean ridge aloft just along the Pacific Northwest coast (fig. 1). The precipitation amounts during the last week of April in Nevada, northern Utah, eastern Oregon, and western Montana exceeded the normal monthly totals for April, but northwest California, western Oregon, and most of Washington and Idaho were still markedly deficient in precipitation. Normally wet Tatoosh Island in extreme northwestern Washington had only 16 percent of its normal April rainfall. The Northwest had considerably subnormal cloudiness (Chart VI–B) and very abundant sunshine (Chart VII–B) during this predominantly dry and mild month.

[3] See Chart I in Monthly Weather Reviews for March, April, July, August, September, November, and December 1950. In most of these months the mean 700-mb. circulation anomalies were very similar over North America and the Atlantic.

REFERENCES

1. J. S. Winston, "The Weather aud Circulation of March 1951," *Monthly Weather Review*, vol. 79, No. 3, March 1951, pp. 50–54.
2. E. J. Aubert, "The Weather and Circulation of November 1950," *Monthly Weather Review*, vol. 78, No. 11, November 1950, pp. 201–203.
3. W. H. Klein, "The Weather and Circulation of the Winter of 1950–51," *Weatherwise*, vol. 4, No. 2, April 1951, pp. 38–39, 46.

THE DEEPENING STORM OVER ILLINOIS ON APRIL 11-12, 1951

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INTRODUCTION

One of the weather forecaster's most difficult problems, of which the synoptic situation of April 11–12, 1951, provides an interesting example, is to anticipate deceleration, stagnation, and later acceleration of a low pressure center, together with accompanying changes in intensity. A newly formed wave, centered about 100 miles northeast of Fort Worth, Tex., at 0030 GMT, April 11, moved rapidly eastward then northward to near Peoria, Ill., deepening as it moved. It then performed a complete counterclockwise loop at greatly reduced speed, after which it moved eastward, accelerated, and began to fill. It is of interest to examine some of the associated phenomena and reasons for unusual behavior of this Low.

SYNOPTIC HISTORY

On April 9 a maritime polar air mass pushed southeastward across the Continental Divide into the western United States. On April 10, the mP front was reenforced by a flow of fresh continental polar air from Canada. The influx of colder air gradually changed the weak pressure field existing over the United States to a field marked by a strong pressure ridge centered over the Great Plains.

On April 10 at 0630 GMT, the push of the maritime polar air brought the front into southeastern Colorado where it was joined to an east-west front separating a modified stagnant mass of cold air on the north from an air mass to the south which was gradually assuming the properties of maritime tropical air.

The upper air picture preceding the storm development over Illinois is given by the 500-mb. chart for 1500 GMT, April 10 (fig. 1). The United States, except for the west coast, was dominated by one large cold trough. The cold Low over Detroit, Mich. was the result of an earlier cold outbreak, and the trough eastward into the Atlantic along the 45th parallel, of still earlier invasions of cold air.

A strong jet from the southwest over stationary ship "Peter" at 50° N., 145° W. turned anticyclonically and entered the continent in the vicinity of Juneau, Alaska. Over Canada, it turned southeastward approximately along the Continental Divide and continued into the United States. Over New Mexico, the jet swung east-southeastward to the northern Gulf Coast and then eastward into the Atlantic Ocean to the vicinity of Bermuda.

Associated with the jet at 500 mb. over the Continental

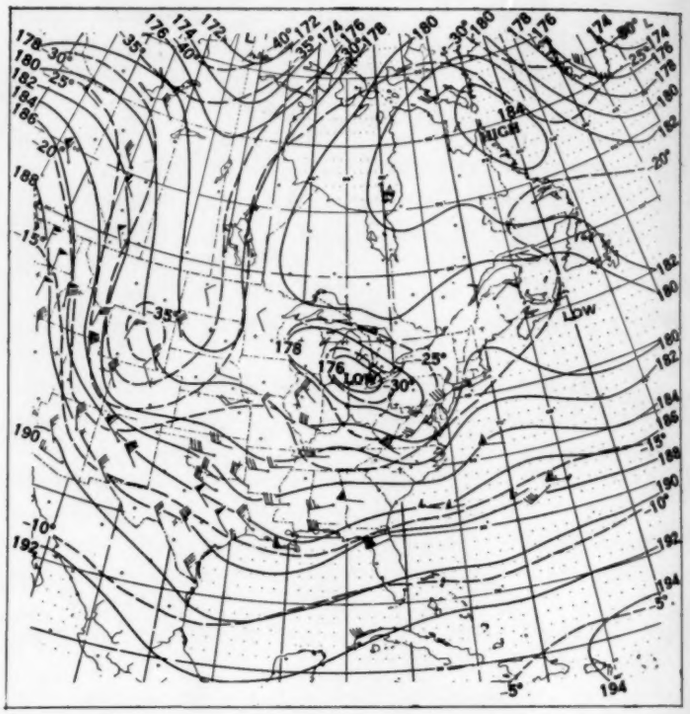

FIGURE 1.—500-mb. chart for 1500 GMT, April 10, 1951. Contours (solid lines) at 200-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are drawn for intervals of 5° C. Barbs on wind shafts are for wind speeds in knots, (pennant=50 knots, full barb=10 knots, and half barb=5 knots).

Divide was a definite packing of the isotherms in such a manner as to indicate strong cold advection into the southern Great Plains States. During the previous 12 hours considerable amounts of cold air had already been brought into the United States as shown by temperature changes at 500 mb. of −10.3° C. at Denver, Colo., −9.3° at Grand Junction, Colo. and −8.7° at Lander, Wyo. Lander recorded the lowest temperature, −34.5° C.

Just to the east of the cold air was a very weak ridge from Oklahoma City to Des Moines, Iowa, with slight warm advection indicated over the Mississippi Valley.

The surface picture leading up to the storm under discussion is given by the surface chart for 0030 GMT, April 11 (fig. 2). The most striking feature of this chart was the flat gradient over the eastern half of the United States with very poorly defined frontal systems, contrasted with the very strong north-south flow from the Dakotas to western Texas. The trough along the cold front in the southwest was elongated with a main center near Del Rio, Tex.

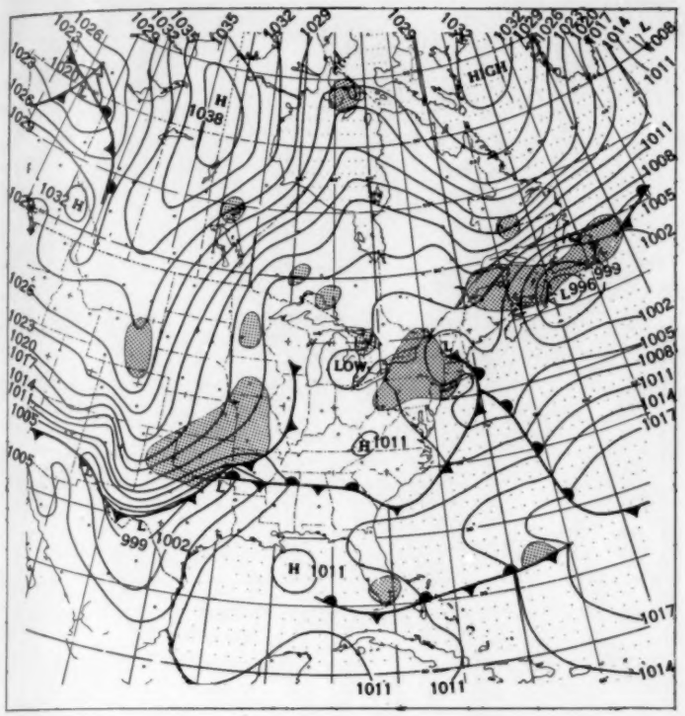

FIGURE 2.—Surface weather map for 0030 GMT, April 11, 1951. Shading indicates areas of active precipitation.

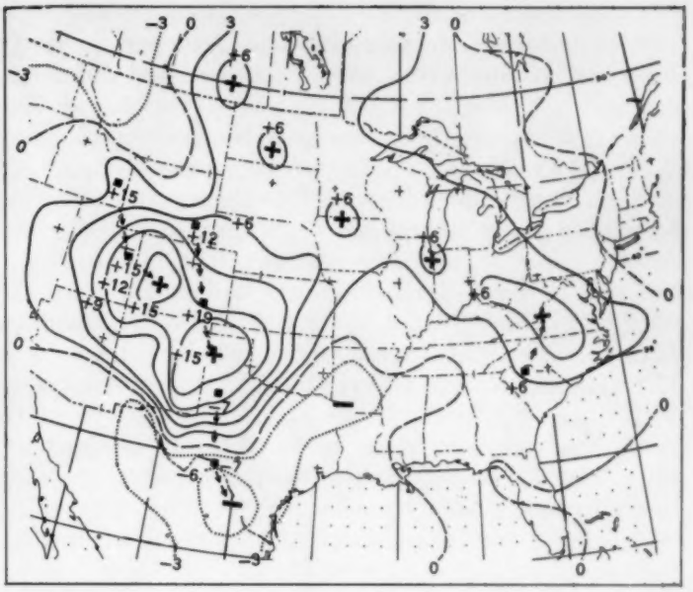

FIGURE 3.—12-hour sea level pressure change chart for 0030 GMT, April 11, 1951. Isolines are for 3-mb. intervals. Dashed lines indicate no change. Dotted lines denote regions of fall, solid lines regions of rise. Tracks indicate previous 6-hour positions. All values are corrected for diurnal variations.

DEVELOPMENT

The 12-hour sea level pressure change chart for 0030 GMT, April 11 (fig. 3), showed a large rise area associated with the cold air over the Great Plains. Two centers of maximum rise were evident, one of 16 mb. near Amarillo, Tex., and one of 17 mb. near Grand Junction, Colo. There was also a general rise area extending from Fargo, N. Dak. southeast into Virginia, evidence of the filling of the cold Low that had existed over Detroit at upper levels (fig. 1), and its replacement by a ridge.

According to Scherhag [1], the rise centers evident over Colorado and Texas (fig. 3) should have moved in the direction of, and with 50–60 percent of the speed of the 500-mb. flow. From the 500-mb. chart for 0300 GMT, April 11 (not shown) an average wind of 60 knots was indicated by the gradient for the area concerned. By applying the above rule, the rise area would have been expected to appear 12 hours later at a point approximately 6 degrees of latitude south-southeast of its position at 0030 GMT, April 11. The centers of rise near Amarillo and Grand Junction (fig. 3) did move, as suggested by Scherhag's forecasting technique, to near Del Rio, Tex. and Alamogordo, N. Mex., respectively.

Evident on the pressure change chart (fig. 3) was a region of falls pushing southeastward on the east side of the Continental Divide into Montana. Here was an indication that the supply of cold air for this system was being cut off by warmer air from the Pacific.

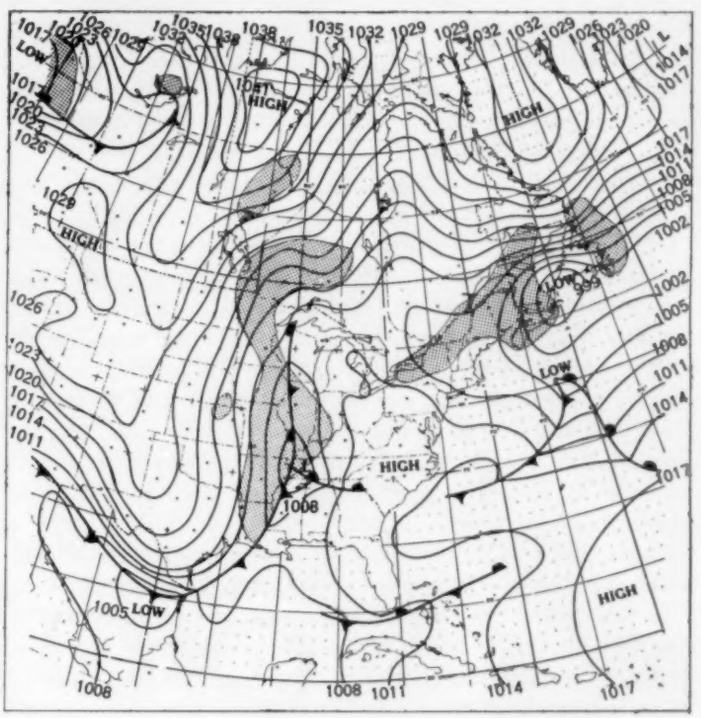

FIGURE 4.—Surface weather map for 1230 GMT, April 11, 1951.

The surface weather picture for 1230 GMT, April 11, 12 hours after figure 2, appears in figure 4. The flow of cold air across Wisconsin and Illinois had been halted, but the cold air continued to be carried deep into Texas and eastward across Arkansas and Louisiana.

The Low that had appeared in the southeastern corner of Oklahoma on the chart for 0030 GMT, April 11 (fig. 2),

as a weakness on an elongated trough, developed a stronger circulation with three closed isobars. A distinct southerly flow became established over Tennessee and Illinois in contrast to the light variable flow shown on the previous chart. The southerly winds east of the Low were intensified by the westward building of the Bermuda High. All of these factors added together brought an ever-increasing amount of warm air into the region just east of the low center.

Figure 5 shows the 12-hour pressure change chart for 1230 GMT April 11, 12 hours after the chart shown in figure 3. The 12-hour fall center of minus 9 mb. near Memphis, Tenn., was a strengthening of the weak center indicated over Arkansas in figure 3. The warm air moving northwestward aloft to the north of the Low joined the warm air from the Pacific over Montana. Thus the deep cold air from Canada was effectively cut off. The region of falls extended from Juneau, Alaska southeastward to Tampa, Fla.

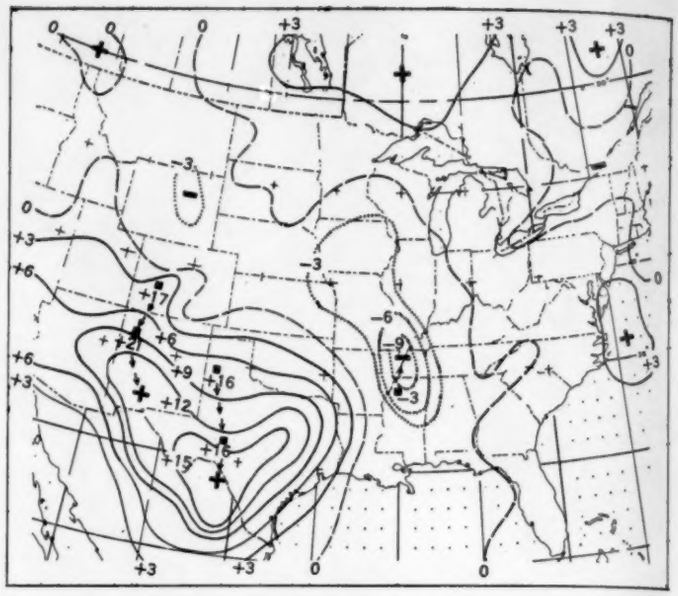

FIGURE 5.—12-hour sea level pressure change chart for 1230 GMT, April 11, 1951.

In support of the suggestion of northwestward flow of warm air, was the precipitation pattern over southern Ontario, Minnesota, and Iowa (fig. 4). Both the steady-type precipitation and the cloud types indicated stable air mass conditions.

The 500-mb. chart for 1500 GMT April 11 is given in figure 6. The trough over the Dakotas (fig. 1), had deepened sharply in the southern end to form closed circulation along the Nebraska-Kansas border. The tongue of cold air carried southward along the west side of the Low showed weakening.

The strong winds over Idaho and Utah in figure 1 spent some of their energy in deepening and accentuating the trough along the leading edge of the cold air (see fig. 6). This is in keeping with the ideas of Wobus and Norton "that a surge of more rapidly moving air parcels, on overtaking the trough line, contributes a portion of its kinetic energy toward sharpening the trough line" [2]. As the trough line sharpened, the winds from southern Texas to the Allegheny Mountains backed and increased in speed.

Associated with the sharpening trough line was the changing thermal structure at 500 mb. Isotherms along the west side of the upper trough became more nearly in phase with the contours while those in advance indicated stronger warming to the east. It should then be expected that the eastward motion of the trough would decelerate and might eventually retrograde [3]. A retrogression or stagnation of the upper trough often results in a similar condition at the surface.

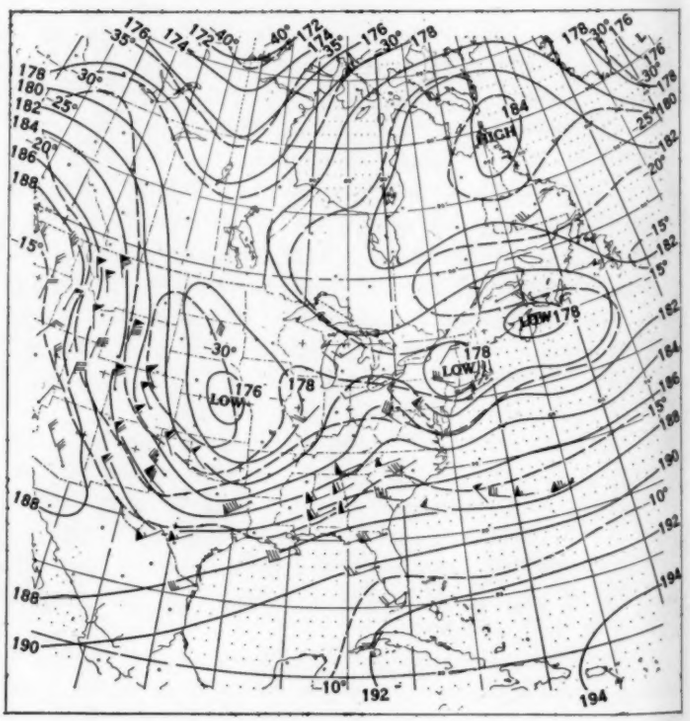

FIGURE 6.—500-mb. chart for 1500 GMT, April 11, 1951.

THE LOOP OVER ILLINOIS

During the 12-hour period from 1230 GMT April 11 (fig. 4) to 0030 GMT April 12 (fig. 7), the Low advanced

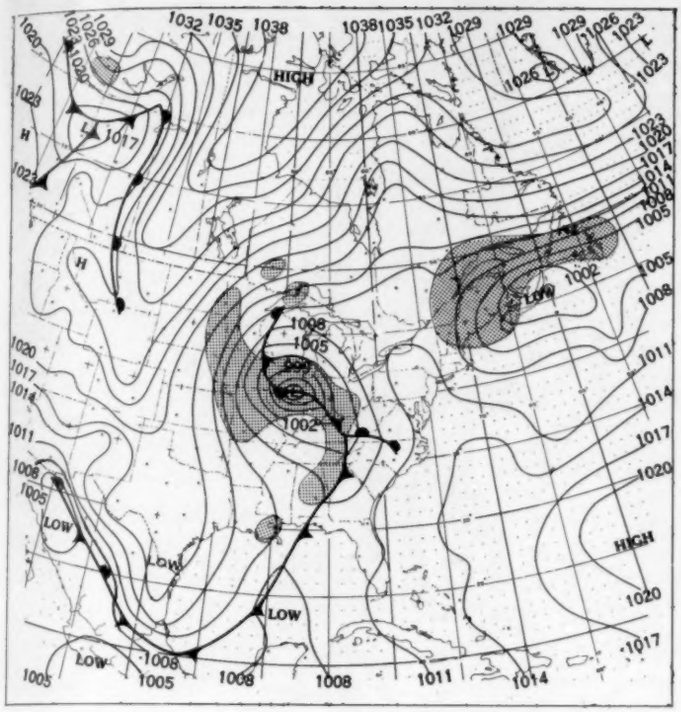

FIGURE 7.—Surface weather map for 0030 GMT, April 12, 1951.

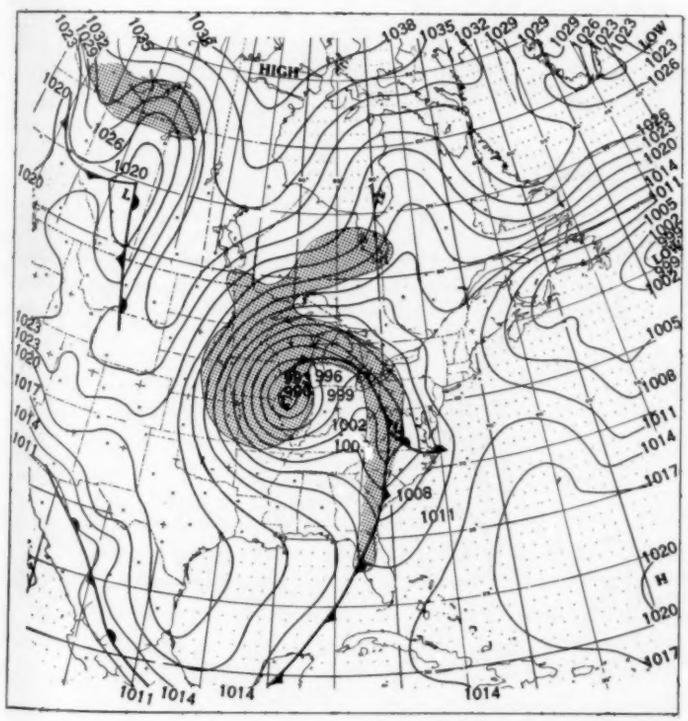

FIGURE 8.—Surface weather map for 1230 GMT, April 12, 1951.

rapidly north-northeastward and deepened 11 mb. From then on, however, there was a decided deceleration in the forward speed, and the surface Low (figs. 8 and 11) moved in a counterclockwise loop around a point about 20 miles northeast of Peoria, Ill. The radius of the loop was approximately 40 miles.

The exact physical processes that went on in the atmosphere to produce this phenomenon are not known. However, some interesting relationships between the surface and 500-mb. systems, bearing on the motion of the Low, will be discussed, and two raobs from Rantoul, Ill., will be examined for changes aloft associated with the surface pressure fall as the Low approached.

Figure 9 shows the track of the surface and 500-mb. centers. The positions for the surface Low at 3-hour intervals and the positions every 12 hours for the 500-mb. level plus the central pressure (mb.) or height (ft.) values in each case are shown. It will be noted that at 1500 GMT of the 11th, the horizontal distance between the surface Low and the 500-mb. Low was about 400 miles. However, at the same time that the surface system was moving northward, the 500-mb. center advanced eastward at 30 knots. At 0300 GMT of the 12th then, the two centers were only 90 miles apart with the axis tilted with increasing altitude toward the south.

By that time, there was a strong closely related cyclonic circulation from the surface to 500 mb. This action had the effect of rotating the tongues of warm and cold air around the almost vertical axis in a manner suggestive of a pinwheel. This is illustrated by the 500-mb. chart for 1500 GMT April 12 (fig. 10). Relative to the upper air center a surface center must move toward the warmer air. Usually the warm tongue assumes a northeast orientation ahead of the upper air trough. In this case, the strong cyclonic circulation carried the warm air to the northwest and finally to the southwest. The surface Low had to follow the movement of the warm tongue as long as the upper level cyclone maintained its intensity.

Finally the warm tongue lost its identity due to adiabatic cooling and mixing within the strong cyclonic circulation (fig. 12). When this happened the axis of the Low became vertical and the path of the surface center was dependent only upon the movement of the upper air cyclone. This phase of the loop is shown in figure 9 from 1500 GMT on the 12th to 0300 GMT on the 13th.

As long as the tilt of the axis of a thermally asymmetric Low has a flat slope with height the speed may be rapid. When the tilt of the axis becomes steep and a strong cyclonic circulation is developed at all levels the speed will decrease and the surface Low may perform a loop. This loop would be expected to be counterclockwise since the warm tongue must rotate cyclonically around the Low. When finally the system becomes a symmetrically

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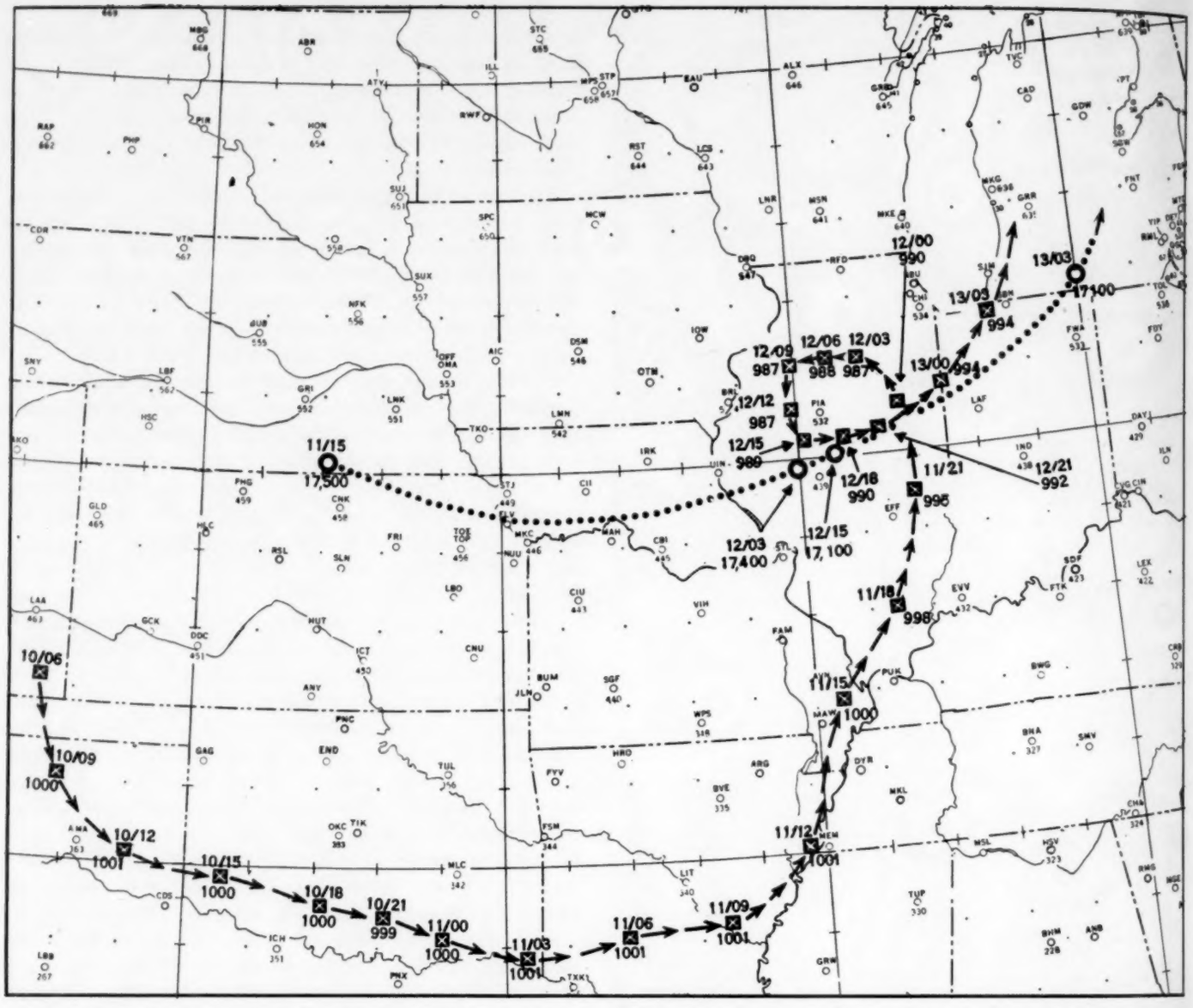


FIGURE 9.—Storm tracks. Small squares indicate 3-hour positions of the surface Low. Numbers above are date and time (GMT). Numbers below are central minimum pressure (mb.). Small circles are 12-hour positions of the 500-mb. Low. Numbers above are date and time (GMT). Numbers below are minimum heights (ft.) at center.

cold Low, the surface Low moves in the direction of the upper air system.

The raobs of 1500 GMT and 2100 GMT, on April 11 for Rantoul, Ill., are shown in figure 13. At 1500 GMT the sea level pressure was 1006.4 mb., with the storm about 230 miles south of the station. During the ensuing 6 hours, as the storm moved northward, the sea level pressure at Rantoul fell 10.8 mb. to 995.6 mb. At that time (2130 GMT April 11) the storm was approximately 60 miles south of the station.

Analysis of the two raobs indicated that there were several levels of slight warming and cooling up to 300 mb. Above 300 mb. the most marked warming was observed. The net warming in the layer from the surface to 500 mb., was counteracted by a cooling of equal magnitude of the layer from 500 mb. to 300 mb. There was enough warming between 300 mb. and 100 mb. to cause a stretching in that layer of 300 feet. The height of the 300-mb. surface fell 310 feet while that of the 100-mb. surface fell only 10 feet. This stretching corresponds to the fall of

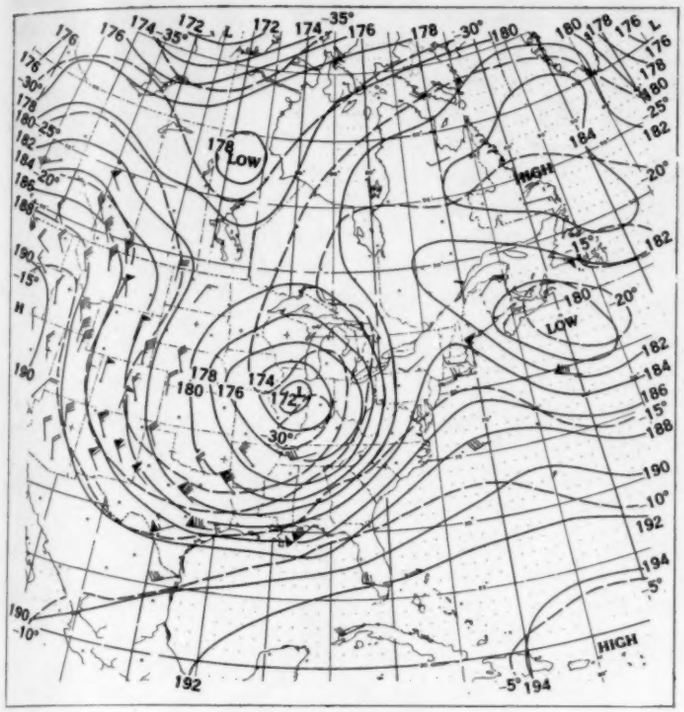


FIGURE 10.—500-mb. chart for 1500 GMT, April 12, 1951.

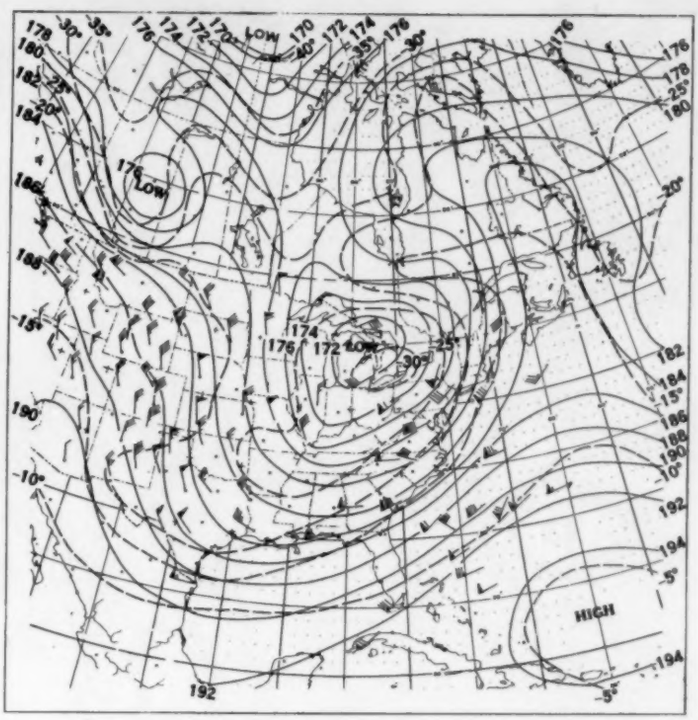


FIGURE 12.—500-mb. chart for 1500 GMT, April 13, 1951.

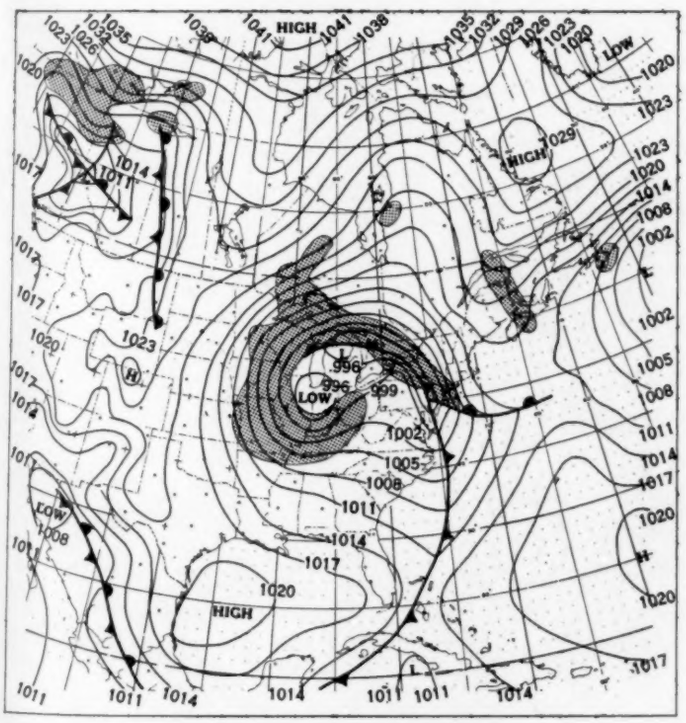


FIGURE 11.—Surface weather map for 0030 GMT, April 13, 1951.

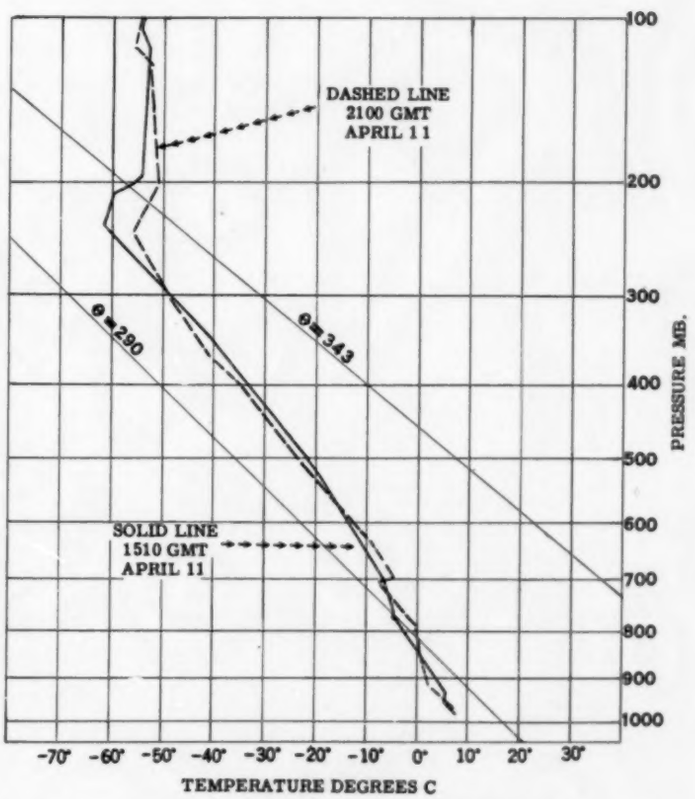


FIGURE 13.—Radiosonde observations of 1500 GMT and 2100 GMT, April 11, 1951, for Rantoul, Ill. plotted on a pseudoadiabatic diagram.

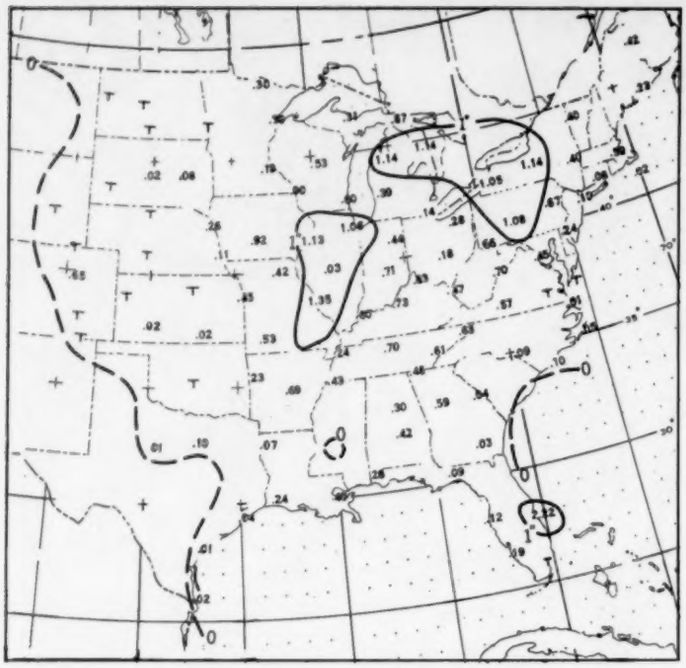


FIGURE 14.—Chart of precipitation amounts for the 48-hour period 0630 GMT, April 11 to 0630 GMT, April 13, 1951. Amounts are in inches.

310 feet of the 1000-mb. surface and a 10.8-mb. fall of the sea level pressure [4, 5].

PRECIPITATION

During the 2-day period 0630 GMT, April 11 to 0630 GMT, April 13, this deep Low produced an extensive area of precipitation (fig. 14). Nowhere was the precipitation very intense but almost all stations east of the Continental Divide recorded at least a trace of precipitation. A large area west of the storm received a late spring snowstorm with snow falling as far south as Springfield, Mo.

The area in excess of 1 inch for this period, covering nearly all of Illinois, was a result of the 24-hour stay of the storm over this area. The larger area over Pennsylvania, New York, and west into northern Michigan probably resulted from a fresh supply of moisture from the Atlantic and the newly developed storm.

REFERENCES

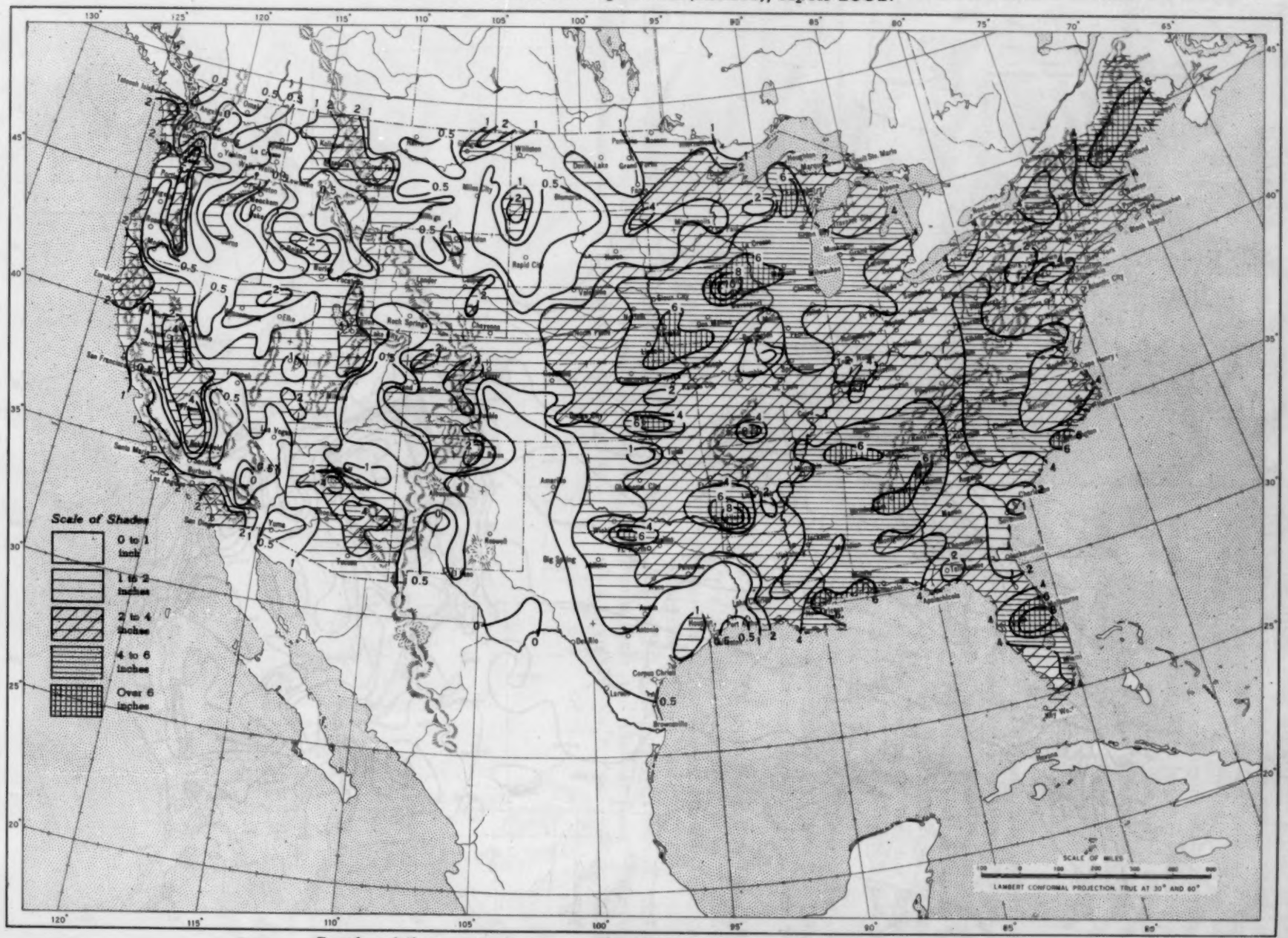
1. Richard Scherhag, *Wetteranalyze und Wetterprognose*, Springer Verlag, Berlin, 1948, p. 268 (English translation, *New Methods of Weather Analysis and Weather Forecasting*, available in Weather Bureau Library).
2. H. B. Wobus and L. C. Norton, "Some Synoptic Aspects of a Change in Weather Regime During February 1950," *Monthly Weather Review*, vol. 79, No. 2, February 1950, pp. 31–50.
3. V. J. Oliver and M. B. Oliver, "Forecasting the Weather with the Aid of Upper Air Data," *Handbook of Meteorology*, McGraw-Hill, New York, 1945, p. 821.
4. J. Vederman, "Changes in Vertical Mass Distribution Over Rapidly Deepening Lows," *Bulletin of the American Meteorological Society*, vol. 30, No. 9, November 1949, pp. 303–309.
5. James F. O'Connor and L. C. Norton, "A Late Season Storm Over the Plateau Area," *Monthly Weather Review*, vol. 78, No. 6, June 1950, pp. 105–111.

U. S. GOVERNMENT PRINTING OFFICE: 1951

Chart I. Average Temperature (°F.) at Surface, April 1951. Inset: Departure of Average Temperature from Normal (°F.), April 1951.

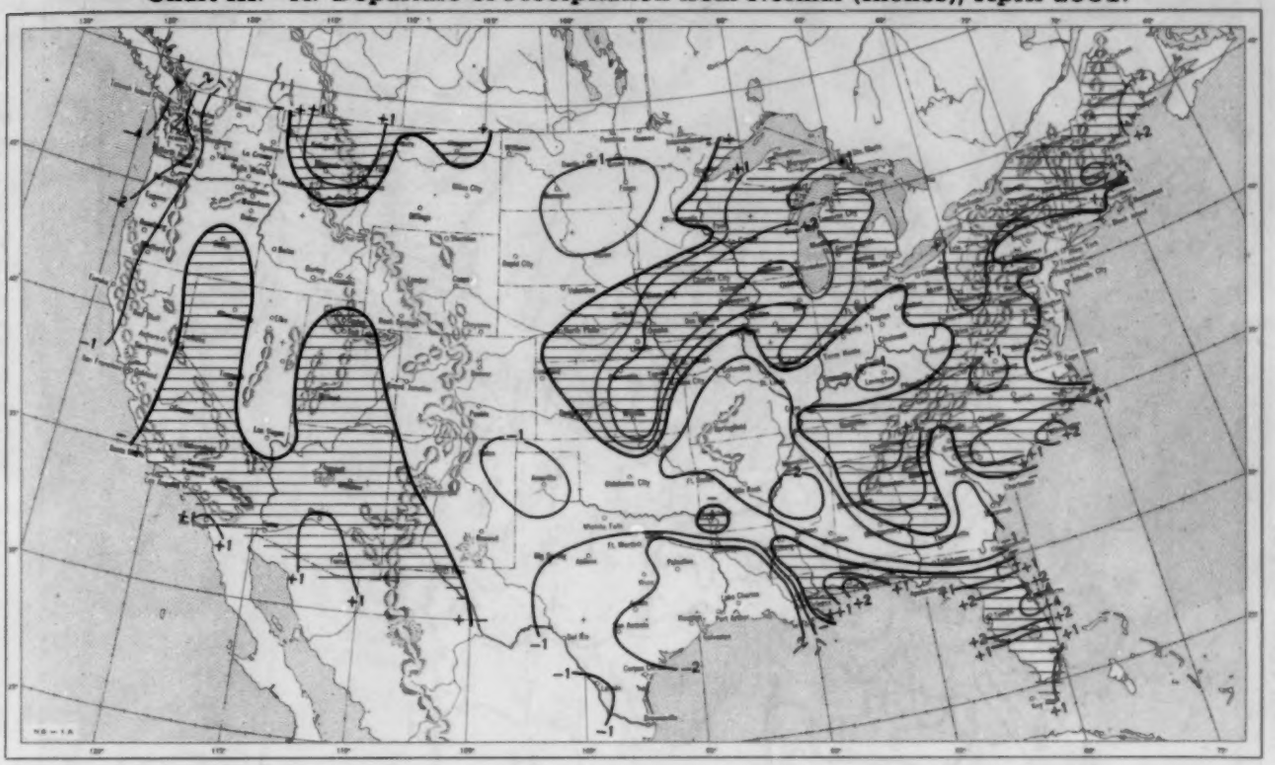
Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), April 1951.

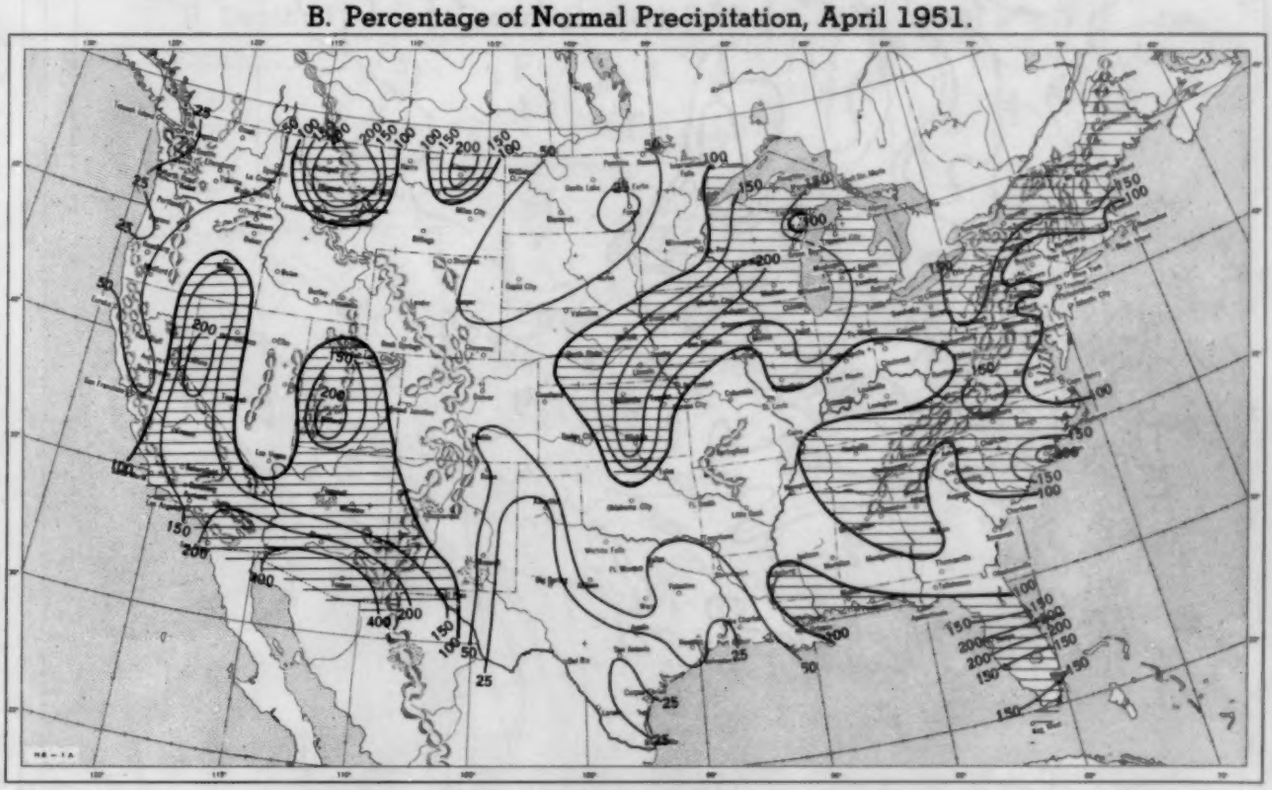

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION, TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), April 1951.

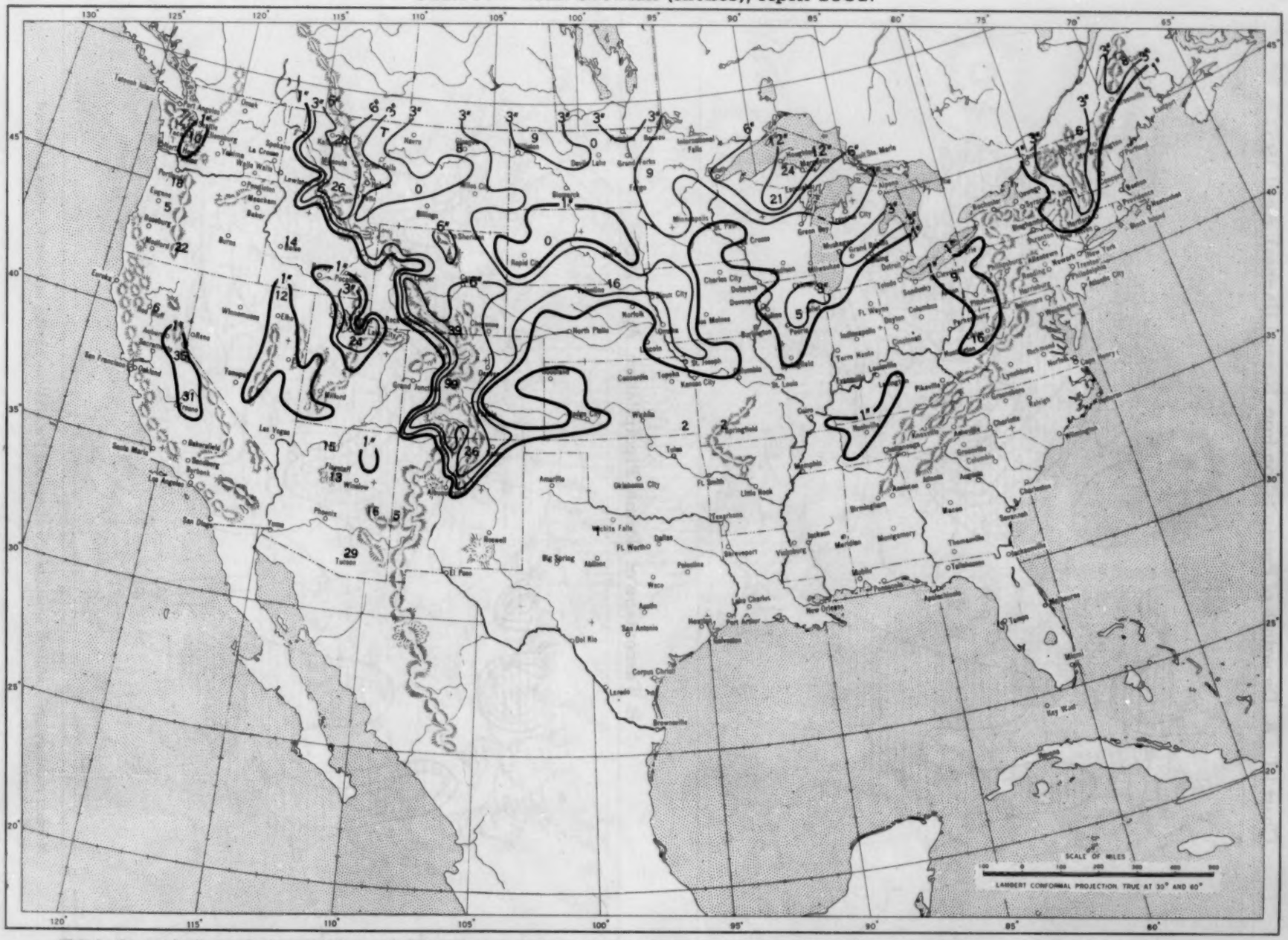


B. Percentage of Normal Precipitation, April 1951.



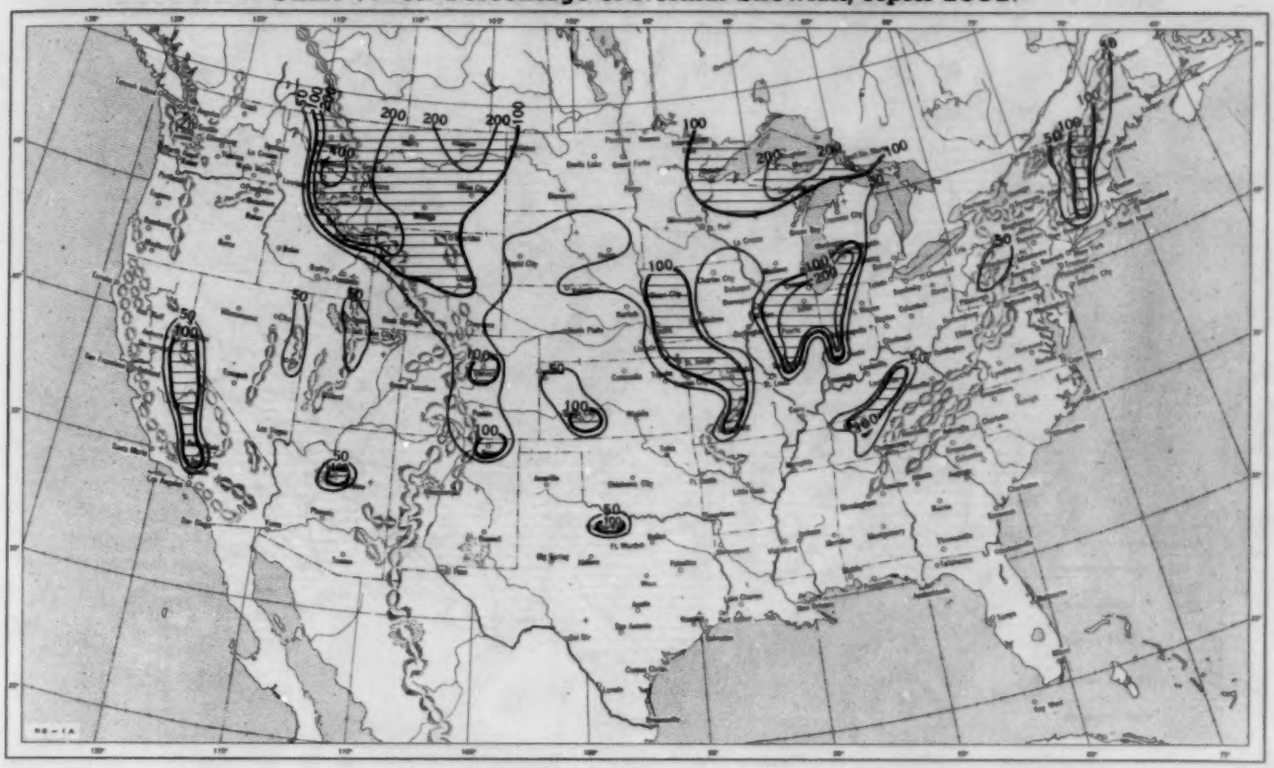
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), April 1951.



This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

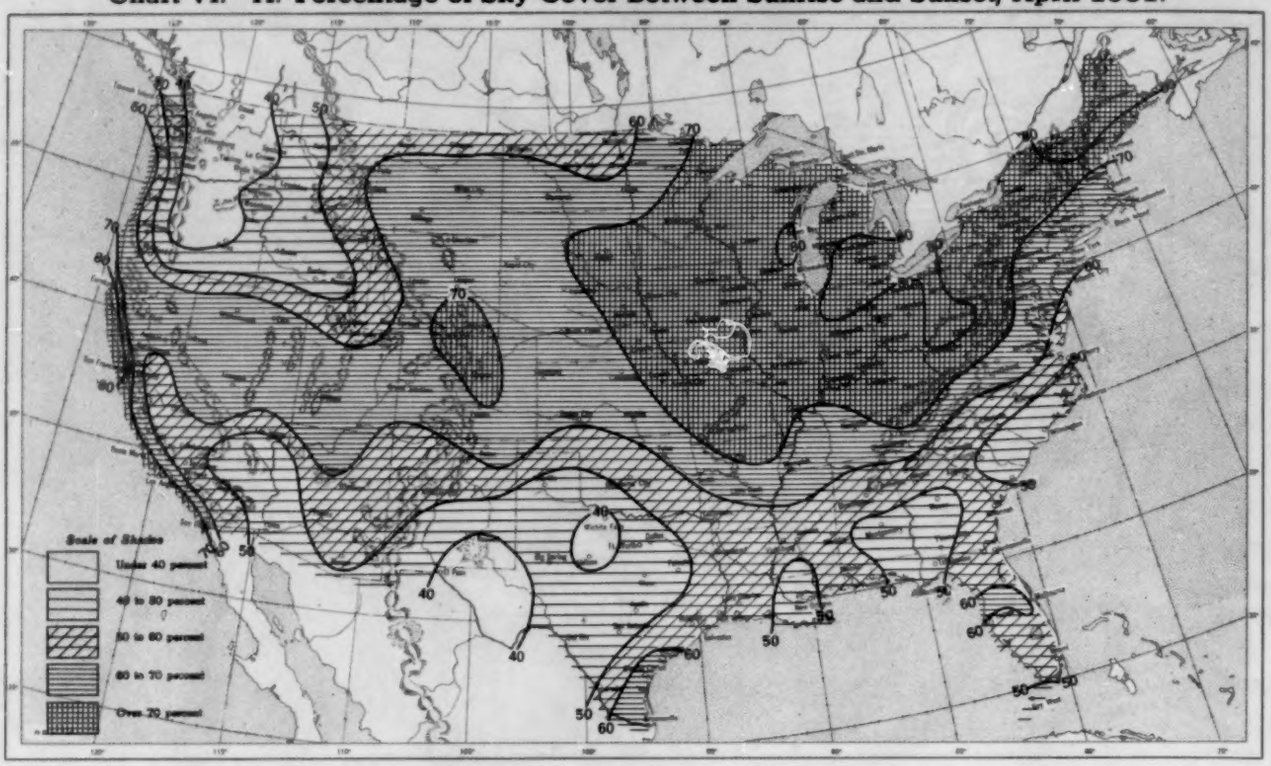
Chart V. A. Percentage of Normal Snowfall, April 1951.



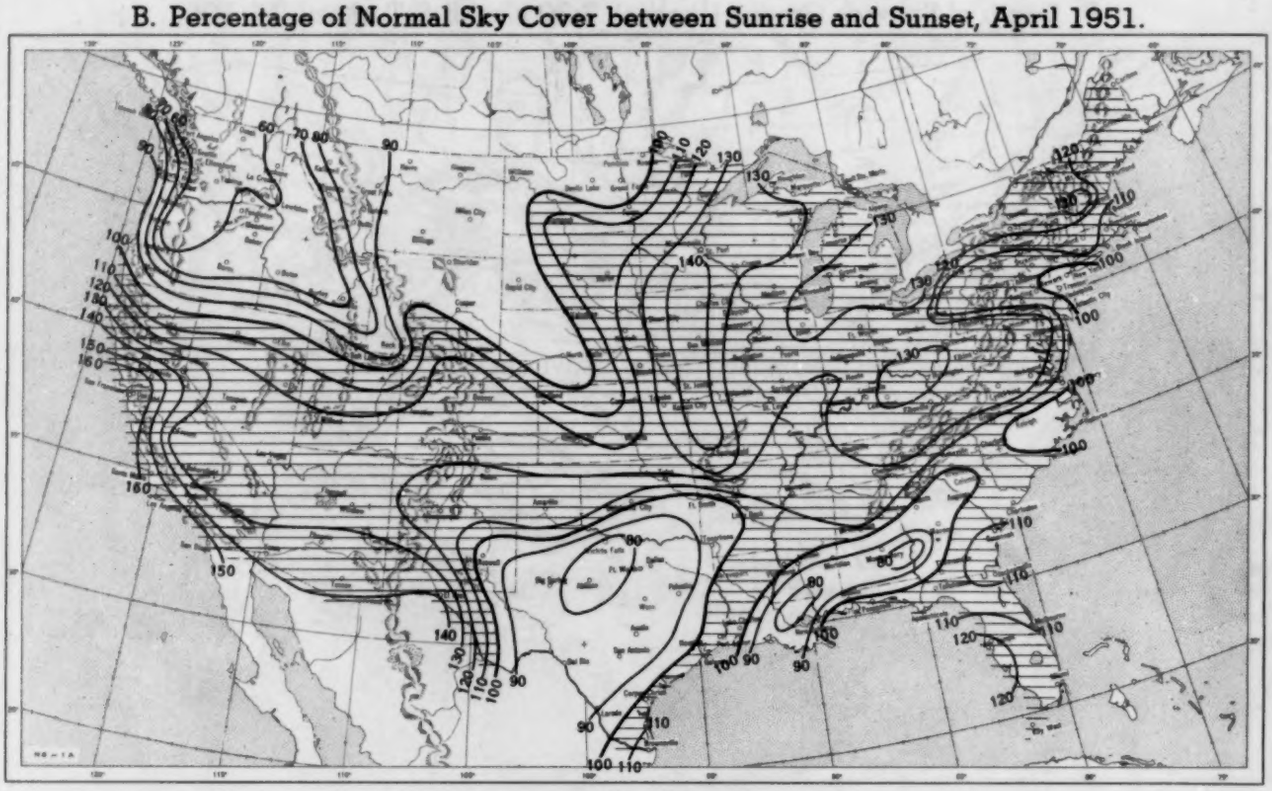
B. Depth of Snow on Ground (Inches), 7:30 a. m. E.S.T., April 24, 1951.

A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record. B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, April 1951.

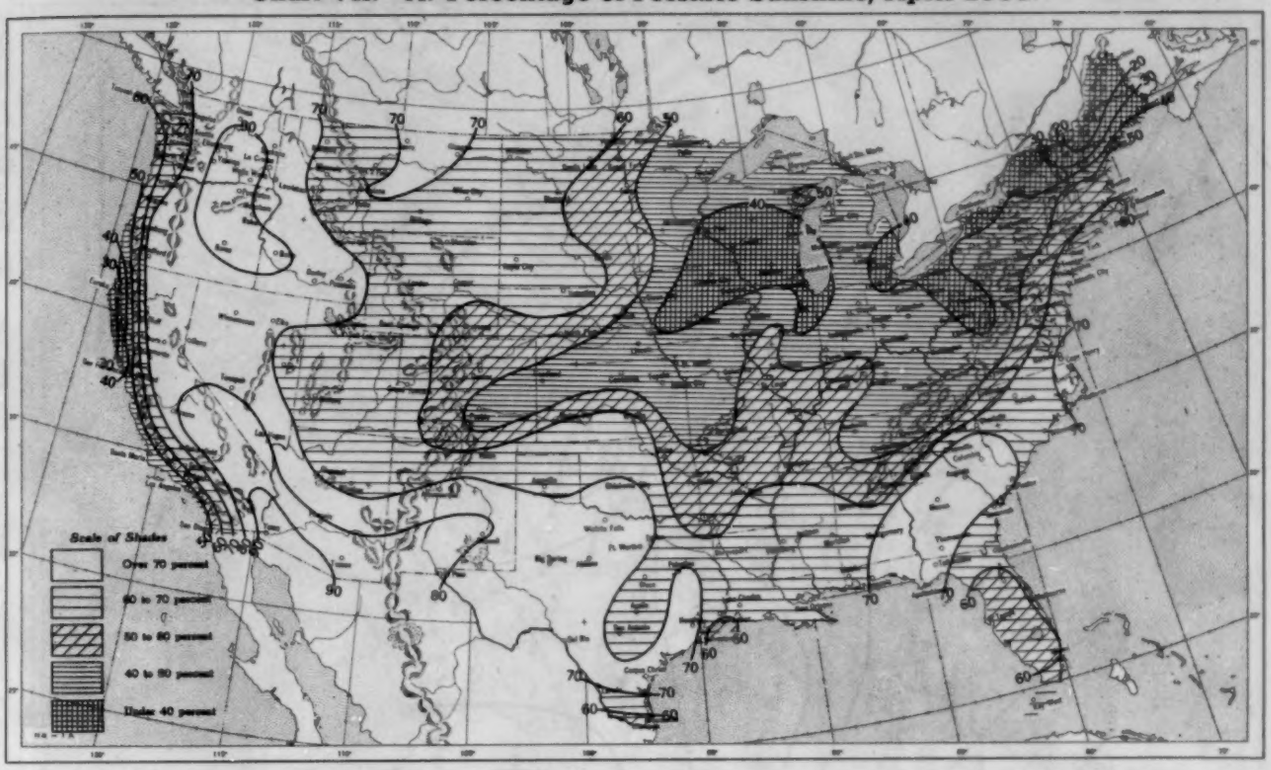


B. Percentage of Normal Sky Cover between Sunrise and Sunset, April 1951.

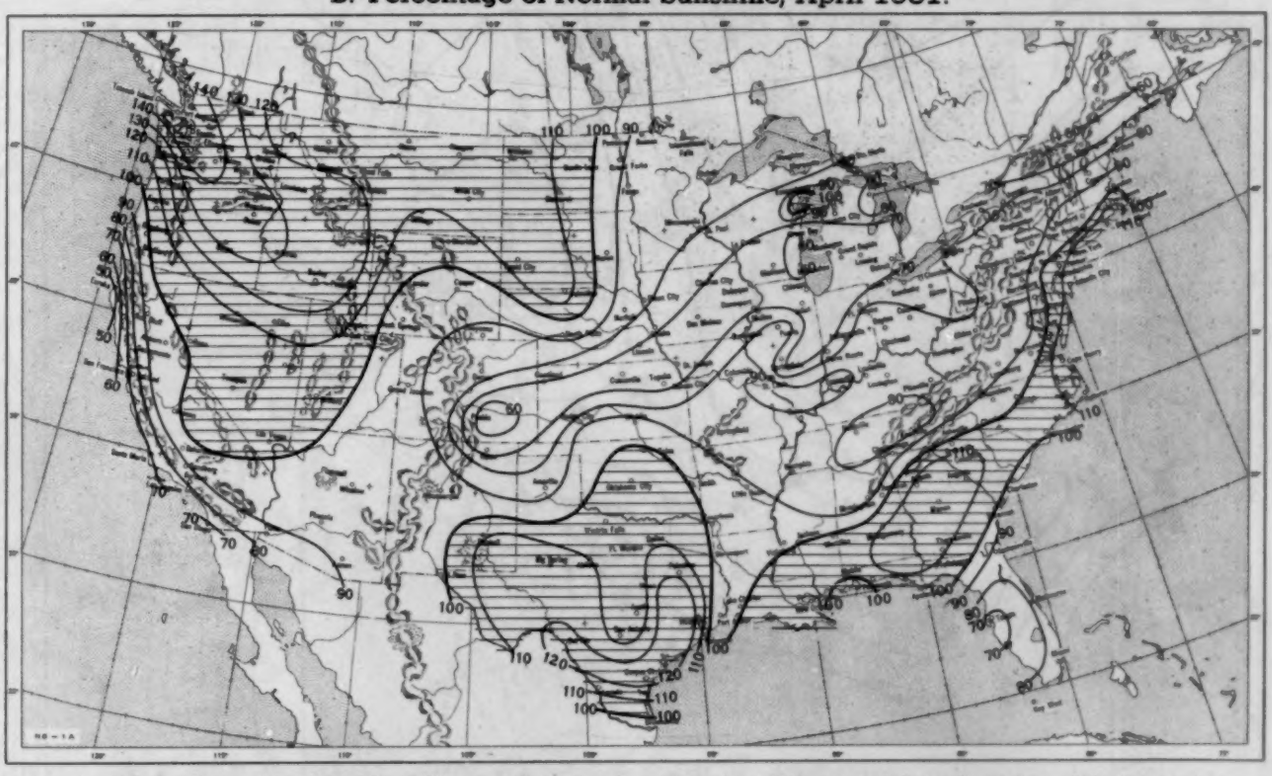


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, April 1951.



B. Percentage of Normal Sunshine, April 1951.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, April 1951. Inset: Percentage of Normal Average Daily Solar Radiation, April 1951.

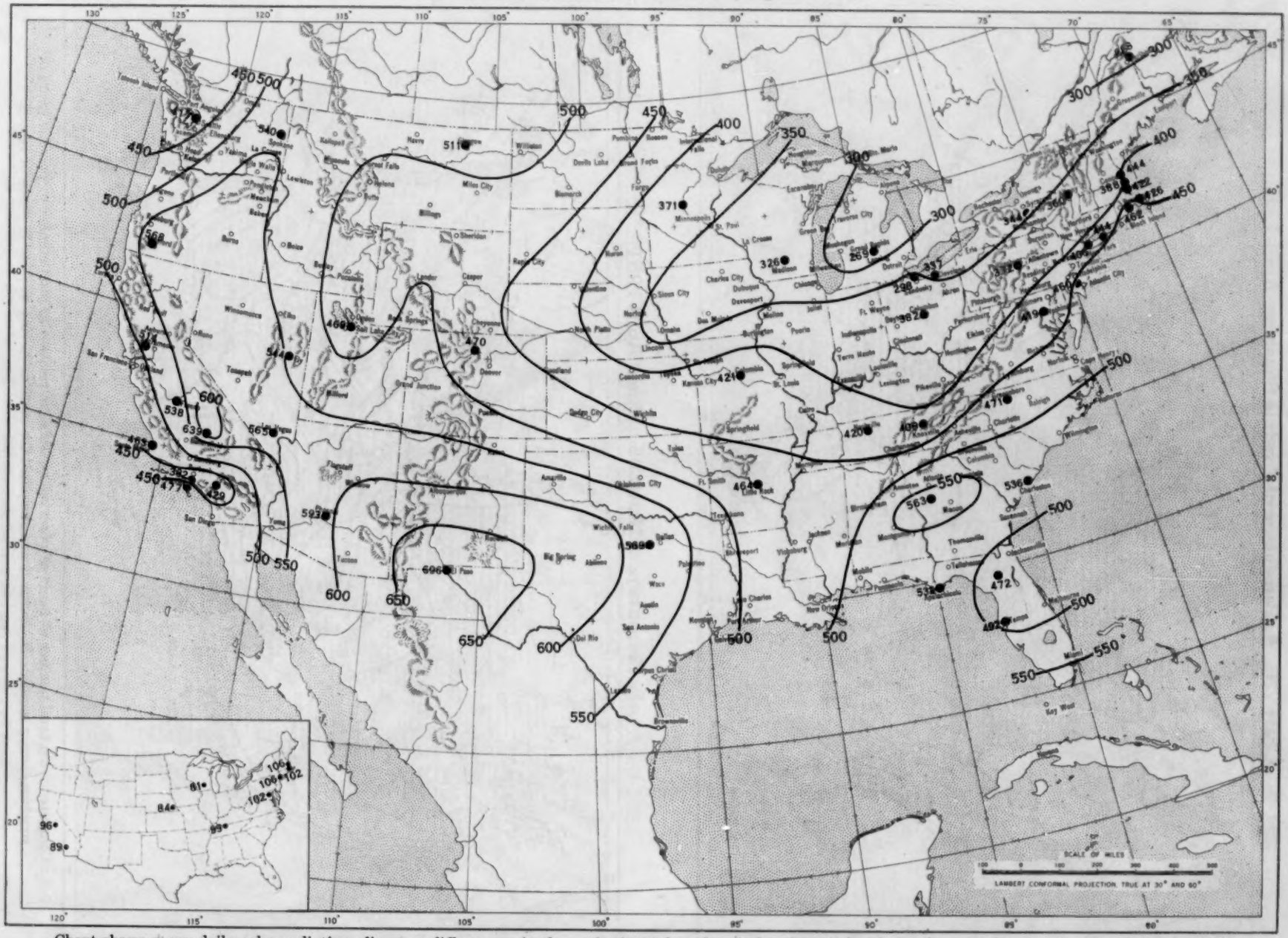
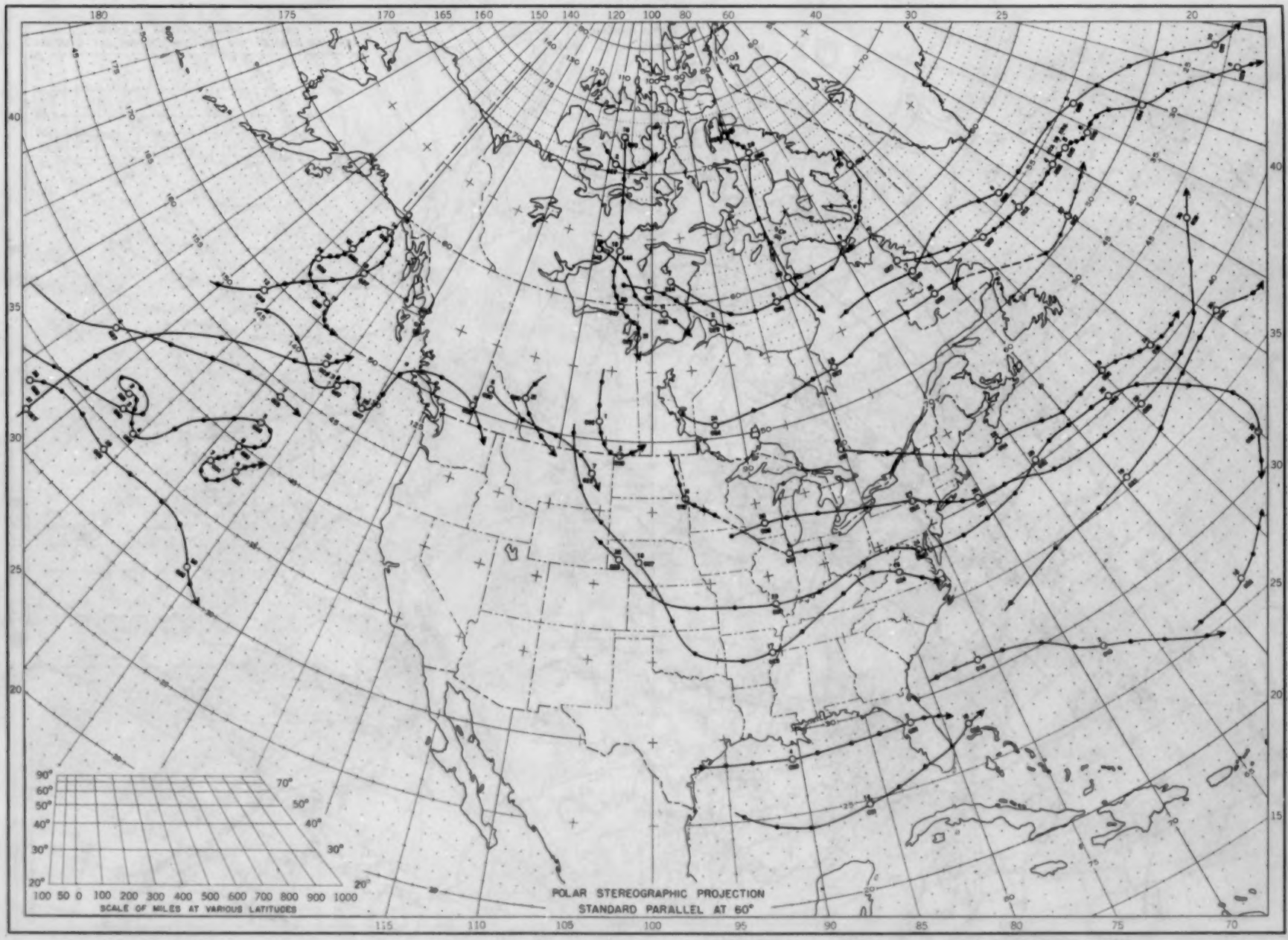


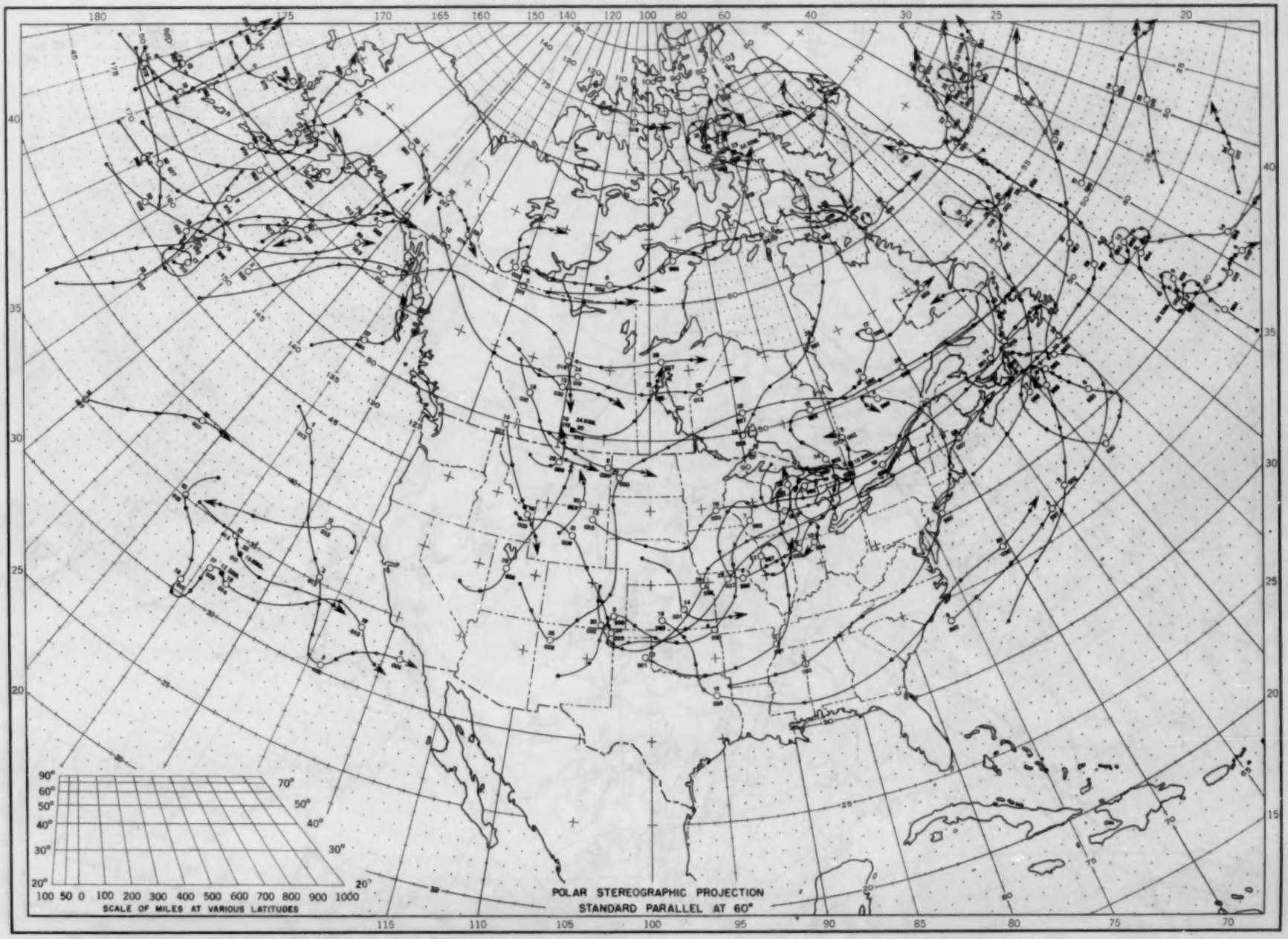
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, April 1951


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

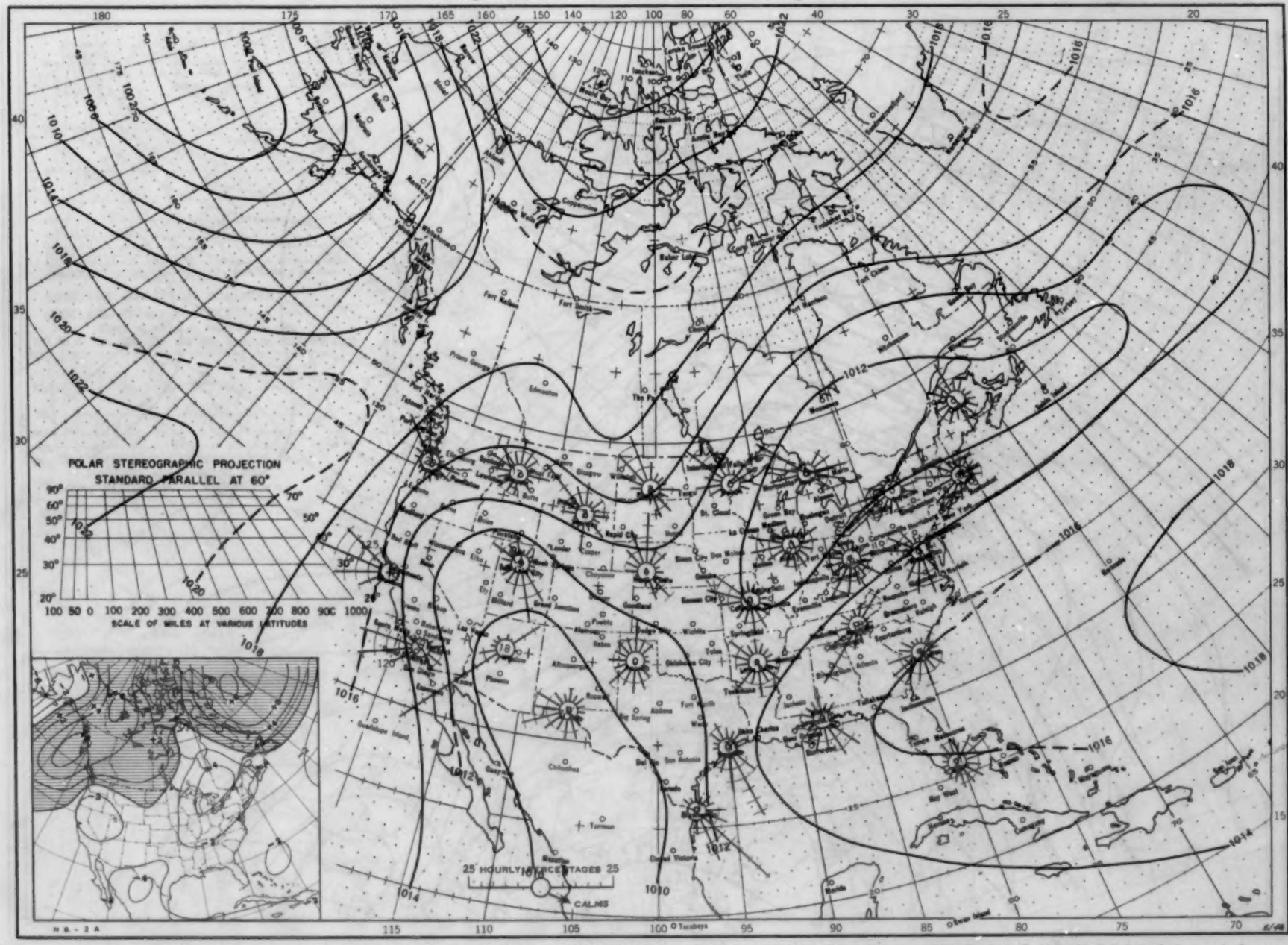
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, April, 1951.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

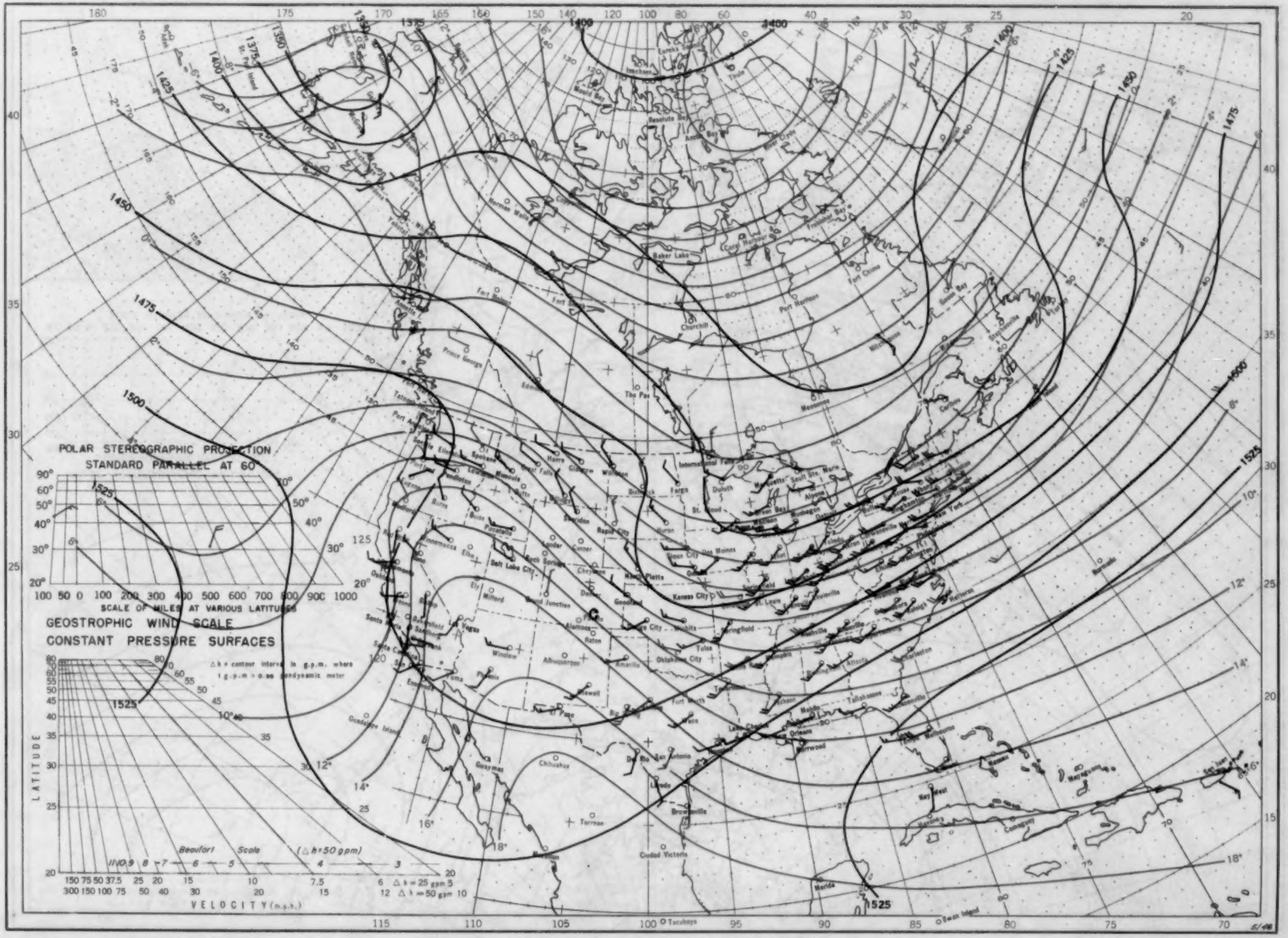
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, April 1951. Inset: Departure of Average Pressure (mb.) from Normal, April 1951.



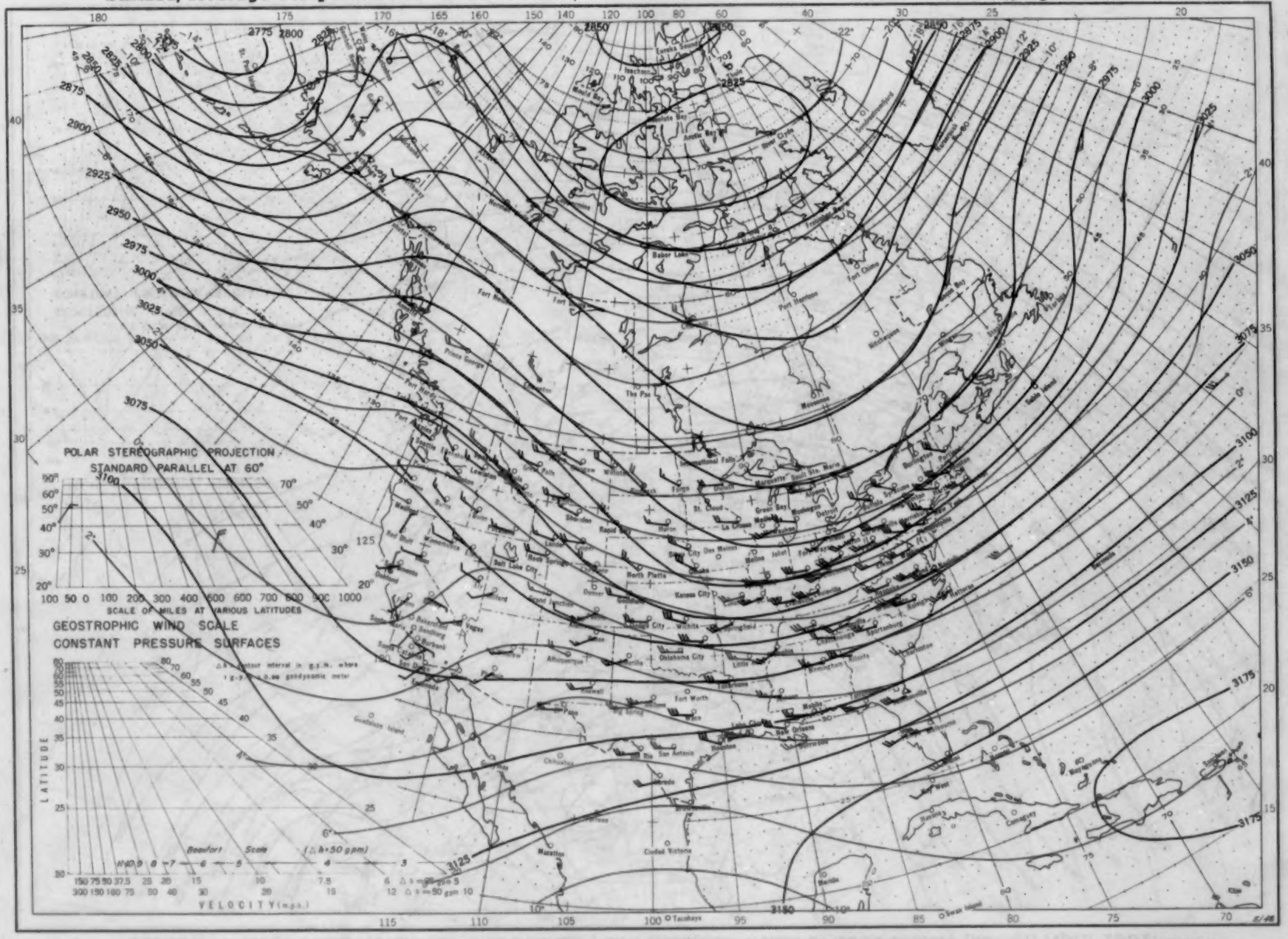
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid from map readings for 20 years of the Historical Weather Maps, 1899–1939.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), April 1951.



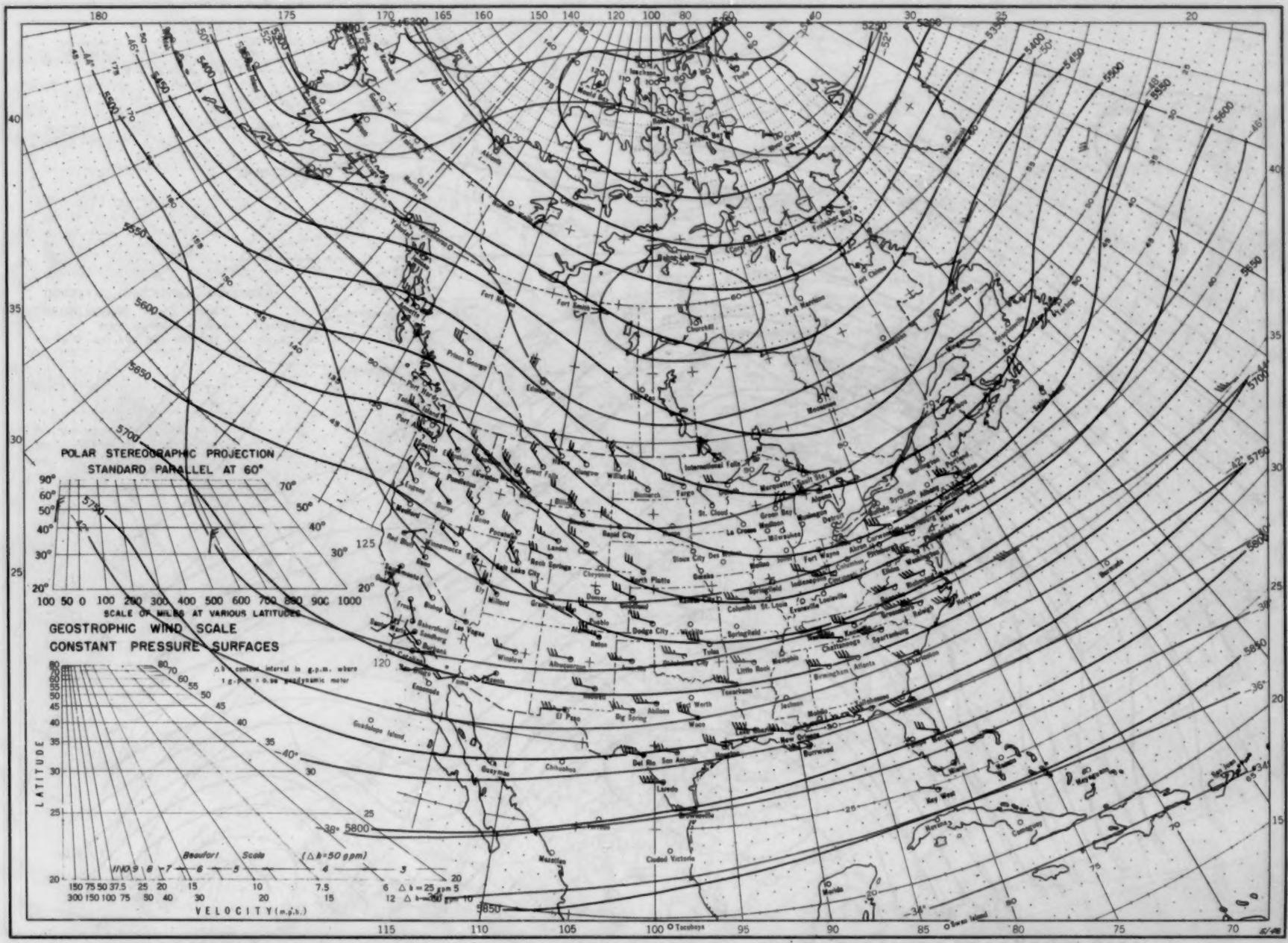
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), April 1951.



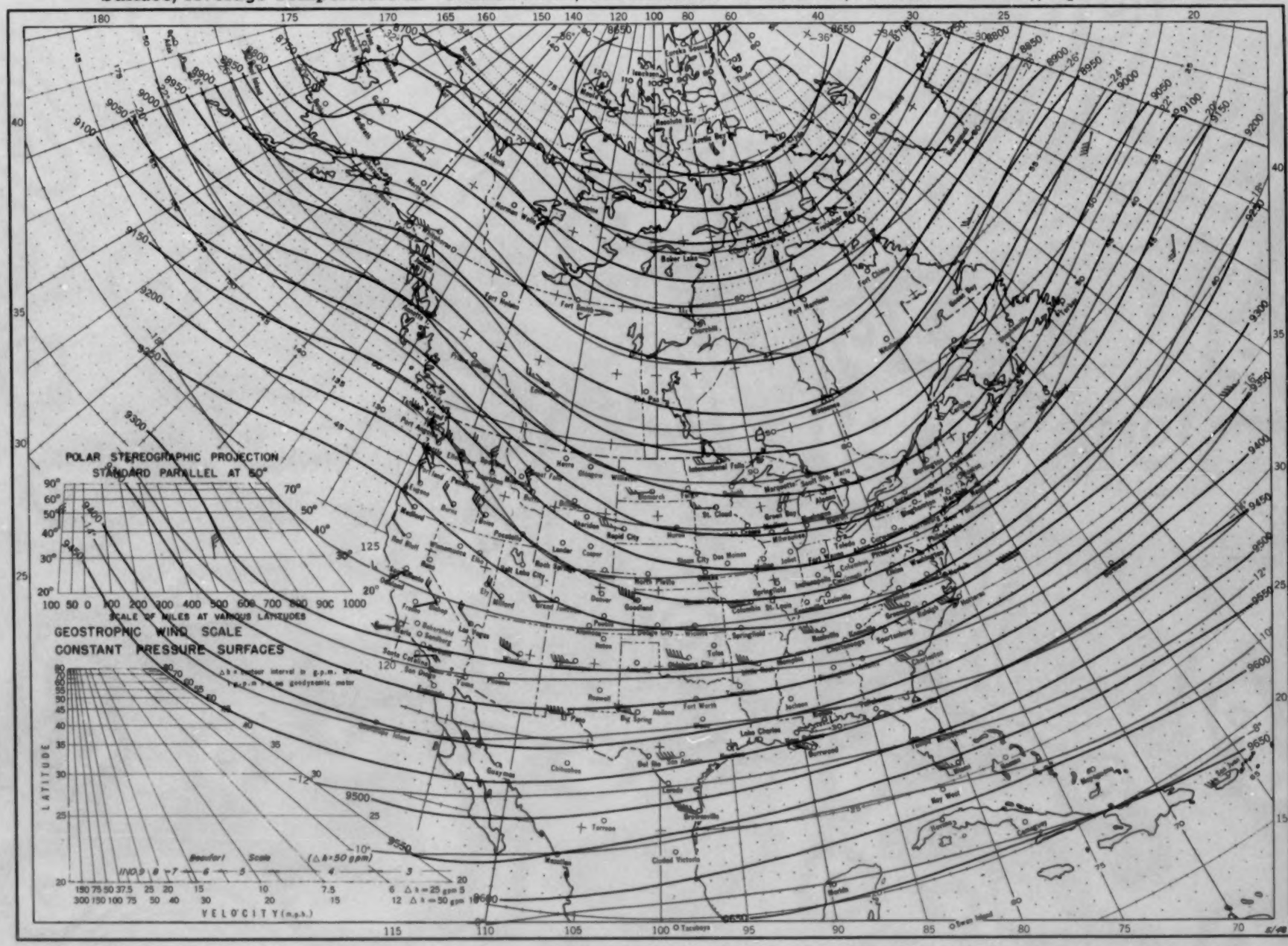
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), April 1951.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), April 1951.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.